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COMPARISON AND EVALUATION OF FOUR THEATER-LEVEL MODELS: CEM IV,--ETC(U)
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WSEG REPORT 299

COMPARISON AND EVALUATION OF FOUR THEATER-LEVEL MODELS:

CEM IV
IDAGAM I
LULEJIAN-1
VECTOR-1

September 1976

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COMPARISON AND EVALUATION

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Chapter I

INTRODUCTION AND SUMMARY

A. INTRODUCTION

1. Purpose

The purpose of this paper is to provide a critical description of four currently available computerized simulations of combat. The paper is intended to be useful to study agencies as an aid in their selection of a model for the study of a specific problem. It should also be useful to the reviewer of modeling efforts in that it makes explicit model assumptions, strengths and weaknesses which may not otherwise be obvious. The

2. Scope

This paper compares all aspects of ~~the four~~ 4 theater-level conventional combat simulations: (1) These models are the Campaign Evaluation Model (CEM IV); (2) the Institute for Defense Analyses Ground Air Model (IDAGAM I); (3) the LULEJIAN I Theater Level Model (LULEJIAN I); and (4) the VECTOR Theater Battle Model (VECTOR I). These models were considered to represent the current state-of the-art by the analytical organizations within the Office of the Secretary of Defense, the organization of the Joint Chiefs of Staff, the Army and the Air Force.

3. Approach

In examining several models one may organize the work vertically, that is by model, or horizontally, that is by aspect. This paper generally adopts the latter scheme and examines the way each aspect, for instance air-to-air combat, is treated in all models before proceeding to the next aspect. For descriptive material organized by model the reader is referred to the

user manuals or to the brief descriptions contained in Chapter II.

4. Basic Descriptions

The functional areas examined in the study are:

- Geographical Theater Structure
- Organization and Missions
- Force Interactions
  - Ground-to-Ground
  - Air-to-Air
  - Combat Air Support
  - Interdiction
  - Air Base Attack
  - Aircraft - Air Defense Artillery
- FEBA Movement
- Logistics
- Unit and Personnel Replacement
- Intelligence

The study also addresses software aspects.

In the appendix to this study, there are papers dealing with the above topics. Each of these papers first describes the manner in which the models treat the aspect being examined to include a tabulation of the major inputs, outputs and assumptions. Each paper concludes with a discussion of the strengths and weaknesses of the various treatments. Consolidated and abridged study results are given in Sections II and III of this chapter.

5. Limitations

There are several limitations:

(1) The study findings are based on the manuals which document each model and not on an analysis of the computer

codes per se or on computed results. It is assumed that the codes match the documentation.

(2) The comparison does not address model improvements which are being implemented. The VECTOR II model which is nearing completion as this is written expands many aspects of VECTOR I. Revised versions of the LULEJIAN model are currently in use but have not been documented. The IDA TACWAR model, to a considerable extent derived from IDAGAM, but with nuclear and chemical logic, is also near completion and should provide improvement. The Combined Arms Simulation Model (CASM) which is under development is expected to constitute a very significant advance in the state of the art.

(3) The study does not evaluate the current data loadings of the models. Although in theory each user could develop an entire data loading for a particular study effort, in fact each model tends to have a standard basic data load which is passed from user to user and in effect has become part of the model. These basic loadings were not examined.

6. A Caution

This study does not have the objective of saying that this model is "good" and that model "bad." The models are tools. In the same vein that a wrench is poor for driving in nails but excellent for tightening bolts, some models may be ill suited for one use but excellent for another. The only purpose of this effort is to aid one in choosing and understanding the appropriate tool.

B. SUMMARY DISCUSSIONS

1. General

Included in this section are brief discussions of the treatment of functional areas by the four models. The discussions include, for purposes of comparison, some characteristics of the models. The lists of characteristics are not intended to be comprehensive; the listed points are those which were considered the most important to the evaluation results. For a more complete analysis of the assumptions inherent in the treatment of functional areas by each of the models, the reader is referred to the appendix to this report.

2. Theater Structure

a. Description

All the models divide the theater into two clearly distinguishable territories by a line called the forward edge of the battle area, or FEBA. Also, all of the models divide each territory into sectors generally following the expected movement of main forces. In all the models except CEM, these sectors are few in number, are fixed, and correspond to the boundaries of some organization, typically a corps. In CEM, up to 1,000 sectors, here called "minisectors," are possible and they can be used as unit boundaries from brigade up to army. Combat operations can cause the organization boundaries in CEM to change, subject to the restriction that they must coincide with some geographical minisector boundary.

VECTOR differs somewhat from LULEJIAN and IDAGAM, in that each battalion sized unit has its own area of operations. Battalions are located geographically only to the sector level; their position within a sector is undefined. This feature is necessary in VECTOR because attrition calculations are made at battalion level.

In none of the models can combat occur across organization flanks. Each model attempts to account indirectly for the problem of exposed flanks. The methods used are FEBA "smoothing," using exposed flank lengths as decision criteria, and, in the case of CEM, the diversion of a portion of available ground forces to the role of flank protection.

None of the models represents the specific location of forces and installations in rear areas. Conceptual distances from the FEBA are reflected in weapons effectiveness values and, to some degree, model sequencing. IDAGAM accounts for the distances from air bases to the FEBA, and, in LULEJIAN the lengths of lines of communications depend upon the FEBA position. IDAGAM and LULEJIAN are also partitioned in depth into three types of areas: combat sectors; regions, which are to the rear of the combat sectors and extend across one or more of them laterally; and a COMMZ (or "base of operations") which covers the entire theater width in the rear of the regions.

Various types of terrain are represented in the models. Terrain types may change laterally from sector to sector, and, in depth each sector can be divided into intervals with differing types of terrain. VECTOR can play the most types of terrain, while CEM allows the most terrain changes, both laterally and front-to-rear. All except LULEJIAN explicitly represent at least one type of militarily significant terrain feature.

b. <u>Characteristics</u>

(1) CEM:

- The specific locations of individual maneuver units on line are represented down to the level of Blue brigade and Red division.
- Precision in the locations of forces is made possible by the lateral division of the theater into as many as 1,000 minisectors, which extend from one end of the theater to the other.

- Laterally, the theater may be divided into as many as 100 terrain "bands," representing changes in the type of terrain. Each of the bands may be divided front-to-rear into as many as 50 terrain intervals representing changes within the terrain band. (There are three general types of terrain, with a fourth type denoting a user-defined terrain feature.)
- The integrity of organization and the chain of command is maintained in the model.
- The boundaries of opposing units are not required to line up across the FEBA, as is the case with most sectorized models.
- Only a single type of major terrain feature, a barrier, can be represented. If multiple barrier lines adjacent to each other are input by the user, major obstacles of varying depth can be represented. The effects of each barrier on firepower scores and movement rates remain the same, however, for a given type of activity.
- A large number of unit boundaries are present, with no combat taking place across them. This is a consequence of the overall model structure which preserves organizational integrity and assesses combat outcome for small units.
- The theater structure and the command and control system in CEM cause difficulty in the representation of major shifts in Blue forces to respond to Red penetrations. These cannot realistically be handled through FEBA smoothing.

(2) IDAGAM:

- The theater is partitioned in depth on each side into three types of areas: combat sectors, regions, and COMMZ. Specific functions and vulnerabilities are associated with each type of area.
- A location in depth is associated with air bases in the regions and the COMMZ. This allows operating ranges of aircraft to be played, along with range-payload considerations.
- Tactical force boundaries are fixed at geographical sector boundaries and cannot change in response to the ongoing situation. On-line forces are located to the sector level only.
- Boundaries of opposing ground forces must coincide; that is, they must line up across the FEBA.

- The type of defensive position employed is a function of side and geography only. It does not depend upon the ongoing situation.

(3) LULEJIAN:

- On each side, the theater is partitioned in depth into three types of areas: combat sectors, regions, and a base of operations (equivalent to a COMMZ).
- The length of the logistics lines of communications varies according to changes in the FEBA positions.
- Major terrain features are not specifically represented. They can be played only by using one of the three general terrain types which are available.
- Tactical force boundaries are fixed at geographical sector boundaries.
- Lateral boundaries of ground forces (sector boundaries) must be the same for both sides.
- Region boundaries for both sides must be the same, i.e., on the same sector boundary.
- The locations of reserve and "fought-out" units are not represented.

(4) VECTOR:

- Terrain is classified in terms of both trafficability and intervisibility. There are five types in each category, for a total of 25 terrain types.
- The theater is divided laterally into as many as 10 sectors. Sectors are conceptually subdivided into areas for each on-line Blue battalion.
- Sector boundaries for both opponents must be the same.
- Tactical boundaries at corps level coincide with geographical sector boundaries, and therefore cannot move as a result of the ongoing situation. Forces can, however, be transferred among sectors by means of the tactical decision rules.
- There are not specific locations within each sector for the battalion areas. They are known only to be somewhere, on line, in a particular sector. Therefore, there is no representation of adjacency of battalions.
- Within a sector the conceptual widths of battalion areas do not change as the number of battalions on line changes.

- The effects of the large number of "protected" flanks for the battalions must be represented indirectly, through the tactical decision rules.

3. Organization and Mission

a. Description

Of the four models, CEM and VECTOR are the most versatile in simulating command and control to determine combat posture. CEM permits a detailed hierarchy of mission selections by each commander in the chain of command which will be used by the next lower level of command. These decisions are based on periodic estimates of the situation and input threshold values. VECTOR has virtually an unlimited ability to simulate command and control by means of user-devised tactical decision rules. This is limited by the resources available to the user to formulate and program the rules. The model permits 17 force posture combinations, more than any of the other models.

The logic in LULEJIAN defines combat posture for individual sectors based on the degree of flank exposure, the criticalness of flank lengths and the success of prior attacks in the sector in question and those adjacent to it. In IDAGAM, the logic permits the selection of theater and sector attackers to be based on relative force ratios and their relationship to input threshold values.

b. Characteristics

(1) CEM:

- Detailed assessments of daily engagement results are used to evaluate alternative courses of action.
- Estimates of the situation are made for each unit at each major level of command.
- Missions of each unit are based on detailed assessments and estimates of the situation.
- Utilization and activities of reserves, boundary widths of subordinate units, and allocation of

fire support are based on estimates of the situation.

- Each ground unit (to brigade level on the Blue side) is accounted for individually.
- There is no representation of communications among echelons of command.

(2) IDAGAM:

- The number of types of units (divisions) which are represented is input by the user.
- Selections of theater and sector attackers are based on the relationship between the actual force ratio and input threshold values.
- Within a sector, all units of a given type are assumed to be in the same condition.
- The type of response by the defender against an attack is a function of geographic location only. It is not dependent on the course of the battle.
- The logic for mission assignment is fixed with no options available to the user.
- Communications and intelligence are not represented.

(3) LULEJIAN:

- Commitment of units to combat is dynamic, based on the course of the battle as it takes place.
- Units of the same type in a given sector are assumed to be in various states of combat effectiveness. Ineffective units are removed from the front lines.
- Units are identified according to nationality.
- The logic for mission selection and combat posture in a sector considers flank exposure and past results in that sector and in the sectors adjacent to it.
- A number of massing options for the initial attack can be evaluated automatically.
- Only three types of units can be represented for each national participant.
- The logic for mission assignment is fixed with no options available to the user.
- No attrition takes place in a sector when neither side attacks.
- There is no representation of communications.

(4) VECTOR:

- Theoretically, there is a good capability to simulate command and control by user-devised tactical decision rules.
- A number of decisions can be made at various points during the execution of each day's activities.
- Estimates of the situation can be made on the basis of actual strengths in the past, to account for imperfect intelligence.
- Up to 17 force posture combinations are possible.
- The time and resources to formulate and program detailed tactical decision rules for command and control may exceed practical limitations.
- There is no representation of communications.

4. Maneuver Unit Interactions

a. Description

The primary results of ground interactions in each of the models are attrition of personnel and weapon systems and the acquisition of territory by one of the combatants. This discussion focuses on attrition; the acquisition of territory, or "FEBA movement," is covered in a separate section.

To some extent, all four models require as inputs to their attrition mechanisms the results of lower-level, higher-resolution models. Only one, VECTOR, makes any attempt to represent internally the physical processes which occur on the battlefield. VECTOR does so for only one of a number of possible combat activities: the assault on a hasty defensive position. Even for that representation, VECTOR also needs inputs derived from high-resolution simulations. The data for the other models must reflect more of the basic mechanics of combat than the data for VECTOR, and none of the models other than VECTOR is at all suitable for establishing basic attrition rates.

Theoretical justifications for the forms of the mathematical equations used to compute attrition are available for

IDAGAM and VECTOR. Such justifications or derivations were not found for CEM or LULEJIAN. Considering the inherent simplifications necessary in theater-level modeling, the absense of rigorous mathematical derivations was not in itself considered of primary importance, as long as the relationships were intuitively plausible. The equation forms were found, however, to imply certain assumptions which could be evaluated in other than a mathematically rigorous way. These assumptions concern primarily the degree of aggregation of the weapons systems and military organizations represented in the models.

Each of the models accepts input data to describe the performance of a representative number of types of weapons. In this respect the differences among the models are minor. On the other hand, the models are quite different in the way weapons are aggregated internally during attrition calculations. IDAGAM and VECTOR maintain the separate identity and effectiveness values of each input type of weapon. IDAGAM weapons performance characteristics are input in terms of daily kill rates for shooter-target pairs. The VECTOR model internally calculates near-instantaneous kill rates for an attack on a hasty defense. Detailed weapons performance characteristics provided by the user are used in the calculations. In LULEJIAN, weapons are aggregated into various groups for attrition calculations, and subsequently disaggregated for output model reports. CEM represents weapons effectiveness, for a given environment and posture, as a set of three firepower scores for each weapon, and represents the total effectiveness of a force as a sum of the scores. The identity of input weapons is thus lost, insofar as their capability to kill opposing weapons is concerned.

A lower level of weapons aggregation allows the use of a model for analyses which cannot be performed when individual weapons identities are lost, e.g., weapons tradeoffs and evaluations of alternative force mixes. Additionally, more information is available to the analyst for detailed evaluation of

model results. For these reasons, the level of weapons aggregation in VECTOR and IDAGAM is judged superior to that of the other two models.

Two general levels of ground force aggregation are represented in the models. Attrition in CEM and VECTOR is calculated for opposing forces of a size no greater than a Blue brigade. IDAGAM and LULEJIAN calculations are made at the sector level, with opposing forces of approximately Blue corps size. When attrition calculations are made for a relatively large force such as a corps, the representations of combat activities below that level must be reflected in the model input data. Such aspects as maneuver and differing successes of lower level units are necessarily a component of a number of input values, for example, kill rates of individual weapons. The assumptions used to generate such data remain fixed throughout the simulated conflict. Therefore, data for IDAGAM and LULEJIAN must in some way account for combat interactions within forces of corps size. An obvious source of data is a lower-level, higher resolution model.

The VECTOR attrition calculations, on the other hand, are made at battalion task force level. The input data for weapons performance is specifically structured to be suitable for that level. Therefore, for the attack on the hasty defense, the model results reflect the ongoing situation at low levels without the burden of a large number of fixed, input assumptions. Assumptions are necessary, however, to extrapolate the combat results at low levels to obtain overall results at the theater level. In the VECTOR model, these assumptions are embodied in the user-specified tactical rules which control decision processes and FEBA smoothing.

With respect to force aggregation, CEM calculates attrition at the level of the Blue brigade, or lower. It shares the advantages of VECTOR in this regard, except that

firepower scores, with their own inherent assumptions, are used in the attrition assessments. The extrapolation of results from lower to higher levels is accomplished through built-in model logic and user-input parameters.

In a theater-level model, attrition can quite logically be assessed at either high or low levels. The choice of models in this respect depends on the preferences of the user, the purposes of the analysis he is conducting, the nature of the fixed assumptions he is willing to accept, and the availability of data. Overall, computations at relatively lower levels are judged to be more versatile, and therefore more likely to satisfy a variety of analytical needs.

b. Characterisitcs

(1) CEM:

- Engagements and attrition calculations take place at the brigade (or its equivalent) level, or lower.
- Attrition of 12 types of tanks, 12 types of armored personnel carriers, 5 types of helicopters, 12 types of anti-tank/mortar weapons, 8 types of artillery tubes, dismounted personnel and artillery personnel is represented.
- Sums of directed firepower scores are used in attrition calculations.
- An input k-factor, which cannot be derived from measurable physical parameters, is used in the exponential attrition equations to relate firepower scores, number of targets, and target attrition.
- Losses cannot be attributed to the type of weapon which inflicted them.
- Attrition of maneuver-unit weapons systems other than tanks, armored personnel carriers, helicopters, artillery tubes, and dismounted infantrymen is not computed directly. Attrition of such systems, e.g., anti-tank weapons, is assumed to be directly proportional to the attrition of dismounted infantrymen.

(2) IDAGAM:

- Attrition equations are applied to individual firing and target weapons, by type, to obtain "potential" losses. Attrition can be attributed to the system inflicting it.
- A variety of optional techniques are available to scale "potential" attrition downward or upward to obtain actual attrition. Overall "actual" attrition can thus be made a function of force ratio.
- Various optional methods of computing force ratios are available.
- The Lanchester forms of the attrition equations are well-known and transparent. Attrition coefficients (kill rates) are modified each day to account for changes in allocations of fire.
- Attrition calculations are made at the sector (corps) level. Therefore,
  - Forces are assumed to be homogeneous across an entire corps front.
  - Maneuver and mobility of units below corps level are not modeled. Their effects must be determined outside the model and reflected indirectly in appropriate model inputs, e.g., kill rates, scaling factors.
- Standard allocations of fires must be input. Only *linear variations from the standard* are computed internally, on the basis of target inventories.

(3) LULEJIAN:

- A direct relationship exists between FEBA movements, the level of attrition, and the number of battalions committed to combat. Attrition caused by air and ground supporting fires is considered along with attrition caused by maneuver unit weapons.
- The ability to locate opposing force elements is modeled. As the locations of opposing elements become more accurate, the effectiveness of weapons increases.
- The effectiveness of maneuver unit weapons can increase as the range to the target decreases.
- The overall results of ground interactions, reflecting supporting CAS, are used as the criteria for choosing aircraft allocations.

- Weapons are aggregated for attrition calculations. For example, the total anti-tank killing potential of ground weapons and aircraft is applied as a single value against a single, average, generic tank. Results are subsequently disaggregated, so that the number of weapons of a specific type which is destroyed is proportional to the number which is vulnerable.
- Attrition calculations are made at the sector (corps) level, with the general implications as noted above for IDAGAM.
- Attrition of only three primary elements of maneuver units is calculated directly: tanks, armored personnel carriers, personnel. Losses of other weapons (e.g., anti-tank weapons) are assumed to be proportional to one of the three primary elements.
- Allocations of fire to target weapons are implicit in the input potential kill capabilities of firing weapons.

(4) VECTOR:

- Combat is modeled dynamically using small (e.g., 40 second time steps).
- Interactions among weapons, by type, are modeled in detail, using basic weapons performance data. Such processes as movement, acquisition, target selection, target engagement, and target destruction are represented explicitly.
- Allocations of fire are calculated internally, on the basis of input priorities and the availabilities of targets.
- Losses can be attributed to the weapon system which inflicted them.
- Supporting fires (e.g., combat air support and artillery) are dynamically represented, and integrated into the ground combat model.
- The dynamic ground combat model is used to represent only one type of activity for each side: an attack on a hasty defense. The results of other ground combat activities are obtained from input look-up tables.
- The relationship between the results of separate, battalion level engagements and results at the theater level must be defined and programmed by the user. (From the standpoint of flexibility, this is considered a positive feature.)

- At the battalion level, a relatively small number of fixed tactical scenarios is available.
- There is no representation of adjacency of on-line battalions. Locations are in terms of sectors only.

5. Air-to-Air Interactions

a. Description

The models vary in the richness of the types of aircraft and the types of interactions which can be modeled. IDAGAM permits the widest variety while CEM is very restricted in both types and interactions treated.

Each of the models chooses equations to describe detection and engagement. The particular equation contains implicit command and control assumptions. The VECTOR equation presumes efficient centralized control of defender aircraft. LULEJIAN assumes the attacker controls the engagement. IDAGAM assumes a random process, without centralized control.

With the exception of LULEJIAN, no geographic saturation based on an attackers ability to overwhelm a defender in a given place is modeled. All models except IDAGAM permit an attacked penetrator to abort the mission.

b. Characteristics

(1) CEM:

- Basic simplicity and clarity, but with simplistic attrition.
- No geography; only two aircraft types, five missions.

(2) IDAGAM:

- Allows user choice of five attrition forms.
- Allows widest selection of aircraft types (ten) and missions (seven) with any combination permitted.
- Interactions are on regional (ATAF) basis with provisions for fractional crossing of regional boundaries.

- Allows two locations for air-to-air interactions.
- No mission abortion.
- Air allocations essentially independent of ground battle.
- Hard to distinguish aircraft quantity from sortie rate.

(3) LULEJIAN:

- Aircraft missions are approximately optimized.
- Geographic saturation represented; total detection can be limited.
- Combat initiated by attacker escorts.
- No interregional variation.
- No crossing of regional boundaries.
- Input data difficult to isolate.

(4) VECTOR:

- Interactions based on groups, not individual aircraft.
- Decision rule structure can permit flexible assignment policies.
- All air combat is one-on-one, and occurs at a single type of location.

6. Combat Air Support (CAS)

a. Description

All models treat air delivered firepower in a manner consistent with ground delivered firepower. In CEM, LULEJIAN and IDAGAM, the air contribution is treated identically to the ground contribution in terms of attrition and FEBA movement.

The VECTOR and LULEJIAN models differentiate between missions to attack maneuver units in contact and to attack support elements better than CEM and IDAGAM.

CEM and VECTOR contain reasonable procedures to allocate CAS sorties. CEM apportions sorties through a command hierarchy which considers mission and intelligence. VECTOR apportions based on variable decision rules and permits sectors

to call for support. The other model procedures are more rigid.

No model treats the target acquisition process well. Only in LULEJIAN is there interplay between ground and air observation at all. IDAGAM lumps all discoordination, missed acquisition, and error into a massive multiplicative factor which reduces CAS effectiveness twenty-fold. Disruption is not modeled.

b. Characteristics

(1) CEM:

- Detailed, multi-leveled allocation scheme is used to allocate sorties.
- Only one CAS aircraft type.
- No coordination of the attack is considered.

(2) IDAGAM:

- Aircraft may carry varied ordnance loads.
- Army reserves can be attacked.
- Requires the use of a discoordination factor.

(3) LULEJIAN:

- Target acquisition is treated separately from target engagement.
- Allocation based on force density only, not on need.
- No attack of reserves.

(4) VECTOR:

- CAS sorties can be preplanned or called in the course of the battle.
- All elements can be attacked.
- Excess demand can occur.
- No target acquisition model; acquisition rate assumed fixed.
- It may be difficult to change tactical decision rules.

7. Interdiction

a. Description

Air interdiction appears to be the most difficult mission to model. Interdiction can include attrition and disruption of reserve forces, destruction of supplies and the lines of communications, and impairment of command and control. All models treat at least one of these aspects, most treat two. None treats all.

All models allow the flow of supplies to be reduced or delayed; however, no model contains reasonable logic on how such supply reduction affects combat capability. VECTOR allows the most forms of supplies to be destroyed and has the decision rule structure which could permit these shortfalls to affect decisions. The other models contain rudimentary assumptions, for example, a 50 percent tonnage shortfall represents a 50 percent efficiency decrement.

IDAGAM and VECTOR allow the attack of reserve forces. The logic in IDAGAM mirrors the IDAGAM CAS logic except for the absence of the "discoordination factor." The user should for this reason be cautious in loading IDAGAM to assure a relative balance between CAS and interdiction effectiveness. CEM and LULEJIAN do not permit attack of reserves.

b. Characteristics

All models lack good logic to predict effect of logistic shortfall.

(1) CEM:

- Interdiction logic is yes/no. Too simple for analytic use.

(2) IDAGAM:

- Both supplies of one type and reserve units may be interdicted.

- Only weapon and supply attrition is modeled. No network degradation.
- Inputs are difficult to calibrate to CAS inputs.

(3) LULEJIAN:

- Allows the attack of supplies and transportation means, each of which may be defended separately.
- Apportionment of sorties to different interdiction missions weak. Sorties should be apportioned such that the marginal return per sortie approaches equality for all missions.
- No representation of choke points.

(4) VECTOR:

- Allows the attack of 45 target types. Keeps account of quantities interdicted.
- No network degradation.
- Effectiveness of interdiction dependent only on aircraft type.

8. Air Base Attack

a. Description

In all models, attack of air bases is synonymous with attack of aircraft on the ground. Other facilities are not destroyed or suppressed.

All of the models aggregate the actual inventory of airbases into fewer notional theater airbases. CEM treats only two airbases, one forward and one rear per side. LULEJIAN is almost as limited, using only two equivalent airfields per side. IDAGAM and VECTOR allow more variety, with at least five airfields at varying ranges per side. VECTOR airfields are not as flexible as those IDAGAM in that each sector has one and only one field.

All models permit sheltering; however, only VECTOR and IDAGAM permit the play of realistic sheltering selection, with valuable aircraft sheltered ahead of less valuable aircraft.

The models all allow point and area fire attack of aircraft on the ground using simple detection and attrition equations. No models allow for changes in attacker effectiveness as a function of topography, delivery tactics, or defenses.

b. Characteristics

(1) CEM:

- Very limited in terms of aircraft types, munitions, number of bases and dynamics of sheltering.

(2) IDAGAM:

- Allows QRA play.
- Permits complete play of sheltering.
- Allows range-payload tradeoff.
- Attacker effectiveness independent of defenses.
- Allocation logic which assigns particular attackers to targets is difficult to discern.

(3) LULEJIAN:

- Airlift aircraft can be attacked.
- No consideration of detection.
- Rigid sheltering logic.
- No variation in mission allocations between regions.

(4) VECTOR:

- Sheltering can vary by aircraft type.
- Due to the sector (corps) related airbasing, theater air massing is discouraged.

9. Interaction Between Aircraft and Air Defense Artillery

a. Description

In all the models except CEM a deep penetrating aircraft can encounter point and area deployed ADA of at least two distinct types. The penetrator is engaged by each of these independently. The effects of differing penetration modes, e.g., corridor bursting, and other geographically related phenomena are not adequately resolved by any of the models.

Two of the models, LULEJIAN and VECTOR, permit penetrators to attack ADA destructively or to provide temporary suppression of ADA. The other two permit only destructive attack, thereby ruling out treatment of ECM.

b. Characteristics

(1) CEM:

- Model is highly aggregated and simplistic.

(2) IDAGAM:

- The user may choose among several attrition equation forms for each ADA weapon and for the suppressor.
- Expenditure of SAM may be limited to inventory.
- Fly-by and attack attrition are differentiated.
- Alternative geographic deployments for ADA are not possible below Army level.

(3) LULEJIAN:

- Some saturation effects are modeled. Sector width is considered in determining detection and engagement probabilities.
- Defense suppression and destruction are modeled.
- A variety of defense weapons locations are considered.
- The inventory of point air defenses contains invarient proportions of different ADA weapons.
- Alternative geographic deployments for ADA are not possible.

(4) VECTOR:

- Air defenses can be differentiated by corps sector.
- The degree of saturation of air defenses is assumed to be constant.

10. FEBA Movement

a. Description

Neither CEM, IDAGAM, nor VECTOR attempt to model movement processes. The daily amounts of FEBA movement in the three

models are based on user-input look-up tables. In general, the rates can depend upon the side attacking, the type of terrain, the type of forces involved, and the outcome of the engagement. In IDAGAM, the force ratio is used directly as a representation of the outcome. In VECTOR, the input rates can be modified according to other desired criteria by means of the tactical decision rules.

The LULEJIAN model does not use input look-up tables to determine FEBA movement. Instead, mathematical relationships are assumed to exist among FEBA movement, numbers of casualties, number of battalions committed to the engagement, the ability of the attacking battalions to locate enemy elements, and the maximum, unopposed movement rates of the attackers. The assumed relationships are used to calculate iteratively the amounts of FEBA movement, along with the values of the related variables. The assumed mathematical relationships are intuitively plausible, but are supported by neither theoretical nor empirical analysis. (The same could well be said of the assumed relationship between force ratio and movement rates, which is used in CEM and IDAGAM.)

FEBA movement calculations are made at the same command level as the attrition calculations. In IDAGAM and LULEJIAN, these are at sector (approximately corps) level, and in CEM and VECTOR, at brigade level or lower. Calculations are made separately for each unit, and the FEBA for each unit can move independently. It is therefore possible that FEBA positions of adjacent units will be such that long exposed flanks are created. Since none of the models allows combat across flanks, the effects of flank exposure are not directly represented.

All the models have methods available to limit the degree of flank exposure. In CEM, IDAGAM, and VECTOR, but not LULEJIAN, FEBA positions can automatically be moved in accordance with input criteria to bring adjacent FEBA positions closer

to each other; that is, to make the overall theater FEBA more nearly a single straight line. In all the models, including LULEJIAN, the degree of flank exposure can be a factor in decisions to attempt to advance or to defend a position. Because of the artificial treatment of flank exposure, none of the models can represent a breakthrough or exploitation by a concentrated force.

b. Characteristics

(1) CEM:

- FEBA movement is determined separately for each Blue brigade and Red division. Depending on opposing force alignments, FEBA movement may be computed for elements less than a Blue brigade or Red division.
- Forces can be diverted to provide security for exposed flanks. While diverted, forces do not engage in combat on the FEBA. They also do not inflict casualties on the enemy, but they suffer casualties as do front line forces.
- FEBA movement is assumed to be a function of force ratio. This is unsupported, as is the methodology used to compute force ratios to determine movement.
- Although intuitively plausible, the method for relating the movement of small units to the status of the overall theater force is inflexible, and cannot conveniently be modified by the user. Therefore, variations in tactics or degrees of resolve cannot be played.

(2) IDAGAM:

- The effects on FEBA movement of ground unit mobility and of the capability to concentrate air support are specifically represented.
- In the computations of exposed flank lengths, provisions are made to account for the protection afforded by poor trafficability across the flanks.
- The degree of FEBA smoothing can readily be controlled through the use of input parameters.
- The amount of FEBA movement is assumed to be directly related to force ratio. The force retios computed by the model are not necessarily compatible with the ratios used in FEBA movement rate curves derived from historical data.

- A single straight-line FEBA is assumed to exist across an entire corps sector.

(3) LULEJIAN:

- An intuitively plausible relationship is assumed to exist among the amount of FEBA movement, the fraction of forces committed, and the fraction of casualties sustained. An iterative procedure is used to calculate those quantities.
- Since FEBA movement is calculated within the model, detailed movement rate tables are not required as inputs.
- Although intuitively plausible, the algorithm for computing FEBA movement is unproven. Neither empirical nor theoretical justification for it is available.
- The FEBA is assumed to be a single straight line across an entire corps sector.
- The decision processes which tend to maintain FEBA positions of adjacent sectors in reasonably close proximity also tend to prevent the development of deep breakthroughs in sectors where the attacker is concentrated. Breakthroughs as such cannot be represented in the other models, but the fact of their occurrence can be recognized.

(4) VECTOR:

- FEBA movement is determined at battalion level, and FEBA positions for each battalion are updated daily.
- FEBA movement rates extracted from user input look-up tables can be modified by means of the tactical decision rules. Movement can thereby be made a function of any desired variables.
- The built-in logic for deriving overall movement of theater forces from the computed movement at battalion level consists of rules for adjusting computed positions to make the theater FEBA smoother. Input tactical decision rules may be used to implement more sophisticated logic if desired.

11. Logistics

a. Description

The logistics function is represented to varying

degrees of aggregation in the four models. In all of the models, the items of equipment (and personnel) which are specifically accounted for can be received daily in the theater of operations from sources external to the theater.

Subsequent distribution of these items to forward areas of operation are generally based on need. Allocation of consumable supplies is similarly based on need in CEM, IDAGAM, and LULEJIAN. In VECTOR, the logic for allocation of supplies is designed and programmed by the user as tactical decision rules.

The models differ in the number of types of supply which are separately represented. VECTOR accounts for 27 types of supplies. CEM can represent only four: POL, two types of ammunition, and all other supplies. Both IDAGAM and LULEJIAN each represent one aggregated type of general supply and separately account for SAM consumption. In its unique modeling of lines of communication, the LULEJIAN model accounts for bridge and engineering supplies to represent road construction capabilities.

Most of the supply consumption processes of the models are similar in that supply consumption rates are input for each type of unit, item of equipment, and/or personnel based on the intensity of their activities. The consumption rates are used as linear multipliers for each activity. VECTOR is an exception during an attack on a hasty defense. When this occurs, each type of ammunition expended by opposing maneuver units is calculated directly. Supply shortages degrade force capability, except in the VECTOR model. Direct comparison of VECTOR to the other models in this respect cannot be made since the tactical decision rules affecting shortages have not been written. However, the detailed supply data generated by the model offers good potential to assess the effects of various types of shortages if users are willing to develop the logic.

The maintenance and repair function is represented in

only two of the four models, this in a very cursory manner. CEM permits a depot maintenance function for the repair of tanks, APCs, and helicopters based on input values for expected fractions of total numbers of each system damaged which can be repaired, depot repair capacity, and length of time to repair each type of system. This can create queues and delays. IDAGAM also permits repair and maintenance, but of ground weapons only. The user inputs the percent of each type ground vehicle which can be repaired per day. However, no queues or delays can be created.

The construction function is represented in only two models, CEM and LULEJIAN, and in a highly aggregated manner. CEM allows construction of barriers and prepared defenses, if the rate of FEBA movement is small. No consideration is given to availability of supplies. The LULEJIAN model permits the construction function to improve the logistics ground transportation network, thereby increasing logistics capacity to the FEBA. This is solely dependent upon the availability of construction materials represented by bridges and not upon engineer battalions to do the work.

b. Characteristics

(1) CEM:

- Outcome of engagements is related to the availability of supplies. As supplies decrease conservation can occur to reduce firepower.
- Rear echelon maintenance and repair of tanks, APCs and helicopters are represented.
- Construction of prepared defensive positions and barriers can be represented in an aggregated way. Construction will take place only in subsectors where the average movement rate does not exceed an input value.
- Consumption of only four types of supply can be represented: POL, two kinds of ammunition, and "all others."

- Transportation is represented as a time delay only.
- In the construction of defensive positions and barriers, no consumption of material is represented.

(2) IDAGAM:

- Outcome of engagements is related to the availability of supplies. As supplies decrease, effectiveness is reduced.
- Supplies in sectors are vulnerable to attack by aircraft and ground weapons; in regions they are vulnerable to aircraft only.
- A constant daily percentage of damaged ground combat vehicles can be repaired.
- Consumption of only one type of supply can be represented. That type is used by each person, ground weapon, and aircraft.
- Logistics network is only generally represented.
- There is no withdrawal of supplies from pools due to the repair function requirements.
- No construction functions are represented.

(3) LULEJIAN:

- Outcome of engagements is related to the availability of supplies. As supplies decrease below a nominal level combat effectiveness decreases.
- A shortage of general supplies reduces the number of maneuver forces and aircraft sorties which can be committed to combat.
- A shortage of major equipment items reduces force capabilities directly.
- Three echelons of supply pools are represented. Supplies are moved along a single pipeline as required with proration of supplies if shortages occur.
- There is an aggregated capability to represent the construction of lines of communication by means of bridge construction in a single pipeline from port to FEBA. Bridge sections and general supplies are consumed in bridge building.
- Only a single, aggregated type of general supplies can be consumed.
- Maintenance and repair of weapons systems are not represented.
- Construction effort is not constrained by availability of general supplies or man-days of effort,

but only by the availability of bridge sections.

(4) VECTOR:

- Up to 27 types of consumable supplies can be represented:
  - Ammunition for maneuver units, nine types
  - Land mines
  - Ammunition for field artillery
  - Air defense ordnance, long and short range
  - Ordnance for aircraft and helicopters, 11 types
  - POL, aviation and ground
  - Other supplies
- The calculation of ammunition expenditures for each maneuver unit weapon is based on attrition calculations.
- Except for maneuver unit ammunition, both the passage of time and the type of activity are considered in consumption calculations.
- The tactical decision rule structure provides flexibility to the user in determing the allocation of supplies and major items of equipment among sectors and elements within sectors. They also permit the user to determine the effects of supply on the outcome of engagements.
- The tactical decision rule structure requires skilled user effort in programming rules for supply allocations and for the effects of supply shortages.
- The representation of the supply network is very aggregated.
- Repair, maintenance, and construction activities are not represented.

12. Unit/Personnel Replacements

a. Description

Each of the models accounts for individual personnel replacements, allocating those which arrive in the theater to replacement pools at various levels. Differing schemes for allocation of personnel replacements are used in the models. All are based on need due to attrition or undermanning. None of them were found to be illogical.

IDAGAM permits the maintenance of a balance between personnel and weapons. Thus, a situation of new personnel without weapons arriving at the FEBA is prevented. This imbalance problem does not arise in LULEJIAN since the only individual personnel replacements treated directly are riflemen. There are no built-in procedures in CEM and VECTOR to prevent imbalance.

The VECTOR model permits the greatest flexibility in personnel replacement policies by use of the tactical decision rules; LULEJIAN is the next most flexible with four replacement policy options. CEM allows two replacement options for Red and one for Blue. IDAGAM has only a single policy.

All the models have adequate aggregated representations of the personnel replacement function. None is suitable for detailed analysis of personnel requirements or policies.

b. Characteristics

(1) CEM:

- Allocations of individual replacements to combat units are based on threshold values input by the user.
- Unit (division) replacements are based on user threshold values. Replaced decimated divisions are returned to parent army pool for later combat.
- There is a capability to portray medical processes, an evacuation policy for the wounded, and the return to combat of personnel who have recovered from wounds. Wounded personnel may be either individual infantrymen or crews of weapon systems damaged in combat.
- Under some circumstances, Blue units can be withdrawn after sustaining given levels of combat losses. Combat doctrine of Red units permits depletion of on-line units and rebuilding of exhausted units in the rear.
- A single individual replacement policy is permitted for Blue, and two for Red.
- Replacements for combat units are not distinguishable according to skills or training.

(2) IDAGAM:

- Individual combat personnel are allocated to units only when sufficient weapons are available.
- Units can be withdrawn from combat for rest and recuperation.
- New individual combat troop replacements are assimilated into units over a period of time.
- No flexibility in individual personnel replacement policies is provided, e.g., in a given sector, individual replacments cannot be assigned to front line units without corresponding assignment to the same type of units in reserve.
- Unit replacement policy is not represented.
- All units of a given type in a particular sector are assumed to be in the same condition with respect to personnel and equipment.
- No medical activities can be portrayed.

(3) LULEJIAN:

- Unit and individual personnel replacement policies are permitted.
- Four optional policies provide flexibility in the allocation of individual replacements. Either a unit replacement policy, an individual replacement policy, or mixtures of both can be chosen.
- The allocation of individual replacements can be restricted so that each replacement goes only to a unit of his own nationality.
- Imbalances between individual personnel replacements and weapon systems cannot be represented since riflemen are the only personnel replacements considered explicitly.
- No medical processes can be portrayed.
- New individual troop replacements are assimilated immediately upon arrival in combat units.

(4) VECTOR:

- The tactical decision rules permit considerable flexibility in individual personnel replacement policies and in the allocation of replacement units.
- Allocation of individual combat personnel replacements to sectors is based on level of activity and user inputs.

- Units may be withdrawn from combat for rest and recuperation.
- Extensive use of tactical decision rules to control the replacement process necessitates skilled programming effort by the model user.
- Inadvertent imbalances between individual personnel replacement and weapons may occur. (Design of tactical decision rules could prevent this.)
- No medical activities are represented.
- New individual troop replacements are assimilated immediately upon arrival to combat units and become fully effective without delay.

13. Intelligence

a. Description

Of the four models, only two, CEM and VECTOR, have any capability to simulate directly the effects of the intelligence process. This is accomplished in both models by using information about the actual enemy situations in previous periods (rather than the current period) to make estimates and decisions for the current period.

The VECTOR model is more flexible in simulating intelligence since the process is controlled by user-specified tactical decisions rules. Any combination of specific items of information or delays may be used depending on the user's desire to increase complexity by designing more intricate rules.

The CEM model logic is fixed, and therefore provides the user with somewhat less flexibility than VECTOR in representing delayed information about the enemy. For the Red side, the user is permitted to vary only the relative weights to be applied to the Blue force information from the two previous cycles. For estimates by the Blue side, the model user has an additional option of considering the weighted average of the current cycle and the one immediately preceeding it.

b. <u>Characteristics</u>

(1) CEM:

- Current intelligence estimates are based on actual enemy ground force strength in recent periods (to represent delays in obtaining information).
- The degree to which more recent or less recent periods are weighted in the intelligence estimates is determined by user inputs. This allows a rough representation of the time required to collect and process intelligence information.
- The intelligence process itself is not modeled.
- Enemy tactical air power cannot be included in the intelligence estimates (only actual is used).

(2) IDAGAM:

- No intelligence capability is possible (not even delays).

(3) LULEJIAN:

- No intelligence capability is possible (not even delays).

(4) VECTOR:

- Tactical decision rules can be used to simulate delays in receiving information about the enemy. Current decisions can be based on the delayed information.
- There is essentially no restriction on the information which can be delayed, nor on the decisions which can be based upon it.
- The intelligence process itself is not modeled.
- The tactical decision rules pertaining to intelligence must be programmed by the user.

C. SUMMARY OF RESULTS

The results of the comparative evaluation of the four models are tabulated below. For each functional area, the models are ranked on an arbitrary scale from 1 (the best ranking) to 10 (the worst). The scale is completely arbitrary, and the numerical ratings have meaning only in relation to each other. An effort was made to establish rankings both horizontally and vertically, that is, to compare functional areas within a given model, as well as to compare each individual area among the four models. However, because of the difficulties associated with comparing quite unlike functions, the rankings among different functional areas within each model are not considered as accurate as the rankings among the four models for the individual areas.

The comparative rankings are necessarily judgmental; no claim is made that they are the result of a quantitative analysis. For a given study application, other investigators might arrive at different rankings. The reader is also reminded that certain functional areas are more important than others, and that relative importance is to a great extent dependent on specific study applications. It is meaningless to add or otherwise manipulate algebraically the various rankings to arrive at some single overall score for each of the models. The table should be used only in conjunction with the more detailed information in this report.

MODEL FUNCTIONAL AREAS

SUMMARY OF RANKINGS
(SCALE 1-10)

FUNCTIONAL AREA	CEM	IDAGAM	LULEJIAN	VECTOR
ORGANIZATION & MISSION	1	4	4	3[a]
GEOGRAPHICAL-LOC	1	4	4	3
INTERACTIONS				
GROUND-GROUND	5	2	4	2[b]
AIR-AIR	7	2	3	4
CAS	6	3	2	2
INTERDICTION	7	5	4	5
GROUND-AIR	8	3	4	4
LOGISTICS	7	7	5	4[a]
UNIT/PERSONNEL REPLACEMENTS	4	7	5	5[a]
INTELLIGENCE	8	10	10	8[a]

[a]Assumes that appropriate tactical decisions rules are programmed by user.
[b]Refers only to the structure used for an attack on a hasty defense.

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Chapter II

BASIC DESCRIPTIONS

Descriptions of the models in this chapter are limited to the more general aspects and features. Mathematical logic and more detailed input requirements for each model are identified in the appendix.

This chapter identifies the more general characteristics and highlights of each model. Specifically, its scope and purpose and a brief description are presented. Similarly, the maximum model capabilities in terms of the number of combat sectors, aircraft types, ground forces, and the like, are listed for each of the models studied.

A. CEM IV

The model is a non-nuclear simulation designed primarily to evaluate the effects of changing force structures on force performance in theater level warfare. The outcome of force interactions is determined in terms of FEBA movement, attrition of personnel, and expenditure of resources.

The model is two-sided, deterministic and capable of simulating land and air forces at theater level. It can consider units as small as a brigade on the Blue side and a division on the Red side in engagements taking place in relatively small geographic subsectors. Exponential equations containing systems' vulnerability constants and requiring firepower scores are used to calculate the results of combat involving units down to the size of Blue brigades and Red divisions on a time step basis. Elaborate command and control can be simulated, with higher level decisions at theater and army level affecting the subsequent lower level decisions at corps and divisions. Decisions regarding Blue force estimates,

missions, reserve commitments, fire support, sector assignment, aircraft allocation, and the like can be simulated. In addition, there is a simplified representation of combat intelligence.

The capability of the model permits input of up to 59 Blue battalion types and 55 Red regiment types, for a total number or 70 divisions (Blue) or 210 brigades, and up to 125 Red divisions. The maximum number of maneuver battalions which can be placed in a Blue brigade is essentially unlimited; however, no more than 15 battalions of given type can be placed in any particular brigade. Identical limitations apply to Red regiments. Each side may have up to eight different types of cannon, which may be incorporated into as many as 15 different artillery battalion types. The maximum number of artillery battalions that can be accommodated is 200 Blue and 250 on the Red side. One direct support artillery battalion, maximum, is allocated to each brigade; however, the type may vary among brigades. A Red division may have up to 5 direct support battalions, of one type only, and they may vary among Red divisions. With respect to geography, up to 1,000 minisectors can be used to organize the theater.

B. IDAGAM I

The model is a non-nuclear warfare simulation of ground and air combat at the theater level. Results of force interactions are defined by FEBA movement, and attrition of personnel, weapons and other resources.

IDAGAM I is a two-sided, deterministic, non-optimizing model of conventional theater-level combat using integrated ground and air forces. For FEBA movement and ground combat attrition, including the contribution from close air support, the model permits the user a large number of options ranging from firepower scores to modified Lanchester-square equations.

Similarly, the attrition resulting from air combat, air base attack, and air defense can be calculated using binomial attrition equations, exponential approximations to the binomials, or either the Lanchester square or linear equations. Attrition occurs in geographical sectors. The sectors are divided front-to-rear into intervals, each having a particular type of terrain and defensive posture associated with it.

The model is able to accept the following maximum resources. Some of the quantities are fixed and cannot readily be altered; others can be changed based on the capacity of the computer core storage (below based on 40 K storage).

(1) People - 3 types: combat, combat support, combat service support.

(2) Weapons - 12 types, including SAMs and AAA.

(3) Divisions - 12 types.

(4) Supplies (other than SAM missiles) - 1 type.

(5) Sectors per side - 8.

(6) Regions per side - 2 Blue, 3 Red.

(7) Terrain - 3 types.

(8) Aircraft - 10 types.

(9) Air munitions - 9 types, for attacking targets on the ground.

(10) Air bases - 2 per region, one in communications zone, permitting simulation of airbases at three different distances from the FEBA.

(11) Aircraft shelters - 1 type in fixed locations.

(12) Aircraft missions - 12 (7 primary, 5 secondary).

(13) Individual number of people, weapons, divisions, aircraft, shelters, SAMs, or AAA of any given type is virtually unlimited.

C. LULEJIAN-I

The model is a non-nuclear warfare model designed to make relative assessments of forces, force deployment options, and

tradeoffs among weapon systems. Outcomes of force interactions are assessed in terms of FEBA movement and the attrition of personnel and weapons.

The Lulejian model is a two-sided deterministic simulation of integrated land and air combat at theater level. It can also be used in evaluating the results of corps level engagements. Ground force interactions are aggregated at the corps level in each sector. Exponential equations using individual weapons performance potentials provided by the user are used to compute FEBA movement and personnel and weapon attrition. In addition, attrition is affected by the separation distance between the opposing units. Survivability is improved as separation distances are increased. Firepower scores are not used as measures of effectiveness. The model uses optimizing techniques to obtain "approximately optimal" allocations of certain resources in the theater. The essential feature of this process is that "enforceable bound" outcomes may be obtained, in that the search process identifies "optimal" policies for each side to guarantee that the outcome will be no worse than some bound, even if a given side knows beforehand his opponent's planned move. An iterative, approximate technique is used.

The maximum number of various elements which can be represented are as follows:

(1) National participants per side - 6
(2) Combat sectors per side - 10
(3) Types of maneuver battalions per national participant - 3
(4) Weapon types per battalion - 13
(5) Artillery types per side - 6
(6) Attack helicopter types per side - 2
(7) Aircraft types per side - 5
(8) Aircraft missions per side - 6

(9) ADA weapon types per side - 2

A total of 45 different type of resources may enter the theater on a schedule as specified by the user.

D. VECTOR-1

The model is a non-nuclear warfare simulation for use in estimating net assessments, examining force deployment options, and analyzing tradeoffs among weapon systems. The outcome of force interactions is determined in terms of FEBA movement and the attrition of personnel, weapon systems, and other resources.

The model is two-sided, deterministic with a capability of simulating integrated land and air combat at theater level. Its level of detail permits simulation of engagements at maneuver battalion level or its equivalent. Modified differential equations are used to calculate dynamically the results of combat in small time steps. Tactical decision rules specified by the user permit him to control the model decision processes.

The model permits the representation of up to ten types of maneuver battalions (or equivalent) for each side, and allows employment of mine fields, artillery forces, attack helicopters, and air defense artillery. Each side may employ up to seven types of tactical aircraft and they may be sheltered or unsheltered at air bases. Up to 25 types of terrain may be represented in terms of different intervisibility (5) and trafficability (5).

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Chapter III

MODEL SOFTWARE

This chapter contains descriptions pertaining to the software aspects of each model. Such things as the availability of model documentation, the various users of the models, and the hardware on which the models have been run are identified. Also, hardware storage requirements, typical running times, and model output are discussed. A comment on input data is also provided for the interested user.

A caveat is provided here regarding the model users identified below. Although an organization is identified with use of a particular model, that model's characteristics and capabilities may be somewhat different from those presented in this study. Because of individual organizational or particular study needs these four theater-level models have undergone varying degrees of modification by individuals within those organizations, or through contracted changes, or both. However, the basic design and structure of each model has been maintained. As a result, although model designations may have remained as identified in the documentation, there may be a degree of difference between them.

A. CEM

The available model documentation is identified in the reference section of this report. It is considered generally adequate for assisting the potential user to run the model. The documentation is particularly detailed in describing the way in which command and control aspects of theater combat are modeled in CEM.

The sole user of the model is the U.S. Army Concepts Analysis Agency (CAA). The model is operational on the UNIVAC 1108 computer. The operating system is level 31. Minimum

storage required is 120K decimal words including overlays. Computer running time is 10 CPU seconds per twelve hour cycle. Detailed model outputs are provided the user. These include the distribution of equipment types, missions decided upon at various echelons, FEBA locations, sector boundaries, current status of all forces and current amounts of personnel, major weapons and supplies. In addition, a composite status file report is presented for each theater cycle presenting current and authorized totals of personnel, major weapons, and supplies, along with losses.

B. IDAGAM

Documentation for the model is readily available (See references). The potential user should find it adequate in understanding and running the model.

Several organizations presently use the IDAGAM model. One user is the Studies, Analysis, and Gaming Agency (SAGA), Organization of the Joint Chiefs of Staff. The model has also been run at the Air Force Studies and Analysis (AF/SA) organization and at the U.S. Army Concepts Analysis Agency. At SAGA, the model is operational on the Honeywell computer HIS 6080, used as part of the World-Wide Military Command and Control System (WWMCC). The operating system is GCOS, Honeywell Release 6.2. The AF/SA used the Air Force Honeywell Multics computer with the level 3.0 operating system. The CAA ran the model on the UNIVAC 1108 computer (Exec. 8 operating system). Minimum storage required is 55K decimal words including all of the overlays. Computer running time is about 25 seconds per day of combat.

The output for IDAGAM is in the form of computer printouts of summaries selected by the individual user. These include a detailed report which is generally used for debugging purpose. Also, a selected set of summary tables per day of combat is

provided. Third, a selected summary report of one page length is generated for the user.

C. LULEJIAN

The model documentation is adequate to permit the potential user to understand and run the model. (See references). The manuals provide users and programmers information on the various algorithms used in the model.

The LULEJIAN model is used presently by two organizations. One is the Office of the Assistant Secretary of Defense (Program Analysis and Evaluation), OASD(PA&E). The other is the Air Force Systems Command. The latter organization has the model operational both at its Headquarters and at the Weapons Laboratory (AFWL). The model is operational on the Honeywell Multics computer in OASD(PA&E), on the Honeywell 6080 computer at Hq AFSC, and on the CDC 6600 and CDC 7600 computer at AFWL. The operating system used on the Honeywell Multics is level 3.0, and on the CDC machines it is FTN FORTRAN 3.3. The minimum storage requirement is approximately 50K decimal words. Computer running time varies based on whether the allocations are fixed or approximately optimized. If allocations are fixed, the model requires about 1.5 seconds CPU time per combat day. Running times can increase substantially when approximately optimum allocations are being generated. Some typical games have required from 20 to 40 seconds CPU time per combat day.

Model output is provided the user in the form of a tape of the values of all important variables which are used or generated by the model. The Report Generator manipulates the information on the tape to provide printed results desired by the user. A wide variety of data can be obtained in available tables which may be selected for printing such as the detailed summary and cumulative results.

D. VECTOR

The model documentation for VECTOR is generally adequate for potential users to run the model (see references). It contains considerably more technical information which is oriented to the programmer analyst than the others. Extensive flow charting of algorithms is typical, as well as cross-referencing of individual variables.

The VECTOR model has not yet been used operationally. However, it has been successfully run on the IBM 370/168, UNIVAC 1108, HIS 6000, and CDC 6400 computers. The minimum storage requirement is approximately 50K decimal words. For typical games, the model requires approximately 11 seconds CPU time per combat day.

VECTOR model output consists of daily and cumulative casualties and weapon system losses, by type, and supply consumption data by type of supply. Current inventories of weapons, personnel and supplies are also listed. All of these data are given for individual battalions (if applicable), and are also presented as sector (corps) and theater totals. Reserve forces are explicitly accounted for. Numbers of sorties flown on each mission are given for each aircraft type. The daily activity of each battalion is shown, along with its daily FEBA position. Attributions of casualties and weapon system losses to the enemy system type which inflicted the attrition are presented.

E. MODEL INPUT DATA

Required data inputs are defined fairly adequately in the documentation for the four models. Suggested methods of deriving the more complex data values are given. In each of the models, individual data elements can be changed between model runs without re-entering the entire data base. The

documentation of CEM is particularly complete in its description of the mechanics of preparing and entering data.

The models differ in their level of aggregation, and thus in the aggregation of data entries. CEM, IDAGAM and LULEJIAN are generally similar in aggregation with comparable, though different, data requirements. (CEM's use of firepower scores as the measure of weapons performance reduces somewhat the quantity of data it requires in this area). VECTOR, on the other hand, is disaggregated in its treatment of ground combat, and requires detailed data pertaining to individual weapons performance. Therefore a larger quantity of data must be input to VECTOR than to the other three models. Depending upon the degree of care and accuracy used in generating the aggregated inputs for the other models, the effort required for VECTOR data preparation can be greater than for the others.

For the VECTOR model, the user is also required to formulate, and program in FORTRAN, the tactical rules which control most of the internal decision processes. The tactical rules provide VECTOR with more flexibility than the other models, but they increase the effort required for data preparation. This is particularly true if complex decision processes are desired.

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APPENDIX

DETAILED ANALYSES OF FUNCTIONAL AREAS

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APPENDIX

DETAILED ANALYSES OF FUNCTIONAL AREAS

GENERAL

This appendix consists of analyses of the treatment by the models of functional areas of theater-level combat operations. For each functional area, each model is discussed separately, and then an overall discussion of the functional area is given. The separate discussion for each model is divided into five parts: a description of the functional area; a list of user inputs to that functional area; a list of inputs to the functional area which are generated by other functional areas in the model;[1] a list of outputs; and a list of assumptions.

[1]These "Inputs Generated by the Model," as they are entitled in the listings, could as well have been called "Internal Variables Generated by the Model." The title used in the report was chosen to emphasize the fact that, with respect to the functional area being examined, the variables are indeed inputs.

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A. THEATER STRUCTURE

1. CEM

The theater is divided geographically into relatively narrow "minisectors," which extend the entire length of the theater. The user may specify as many as 1,000 minisectors. These provide the basic structure upon which geographical information and the location of ground forces are based. The minisectors provide the link between physical geography and the locations of ground forces.

Three types of terrain can be represented in CEM. A fourth type is reserved to represent a single kind of terrain feature, for example, a river. In width, the terrain is described in terms of "terrain bands," which extend across an input number of minisectors. Each terrain band is the same number of minisectors wide and there may be no more than 100 terrain bands in the theater. The terrain bands are divided front-to-rear into intervals, so that the terrain within each interval is of a single type. As many as 50 intervals may be represented for each terrain band, with the interval boundaries separating different types of terrain. Interval boundaries for adjacent terrain bands need not line up with each other.

Ground forces are located in terms of the minisectors. The locations of force elements from theater level down to brigade (or equivalent) level are represented. Boundaries between units must necessarily be on a minisector boundary. (Of course, not all minisector boundaries will also be boundaries between force elements at any given time.) The boundaries of opposing force elements need not coincide; that is, they may be on different minisector boundaries.

The initial locations of forces which are present in theater at the beginning of the campaign are specified by the model user. The front line locations of units which arrive later are

determined by internal model logic, with parameters supplied by the user. In addition, organization boundaries may be changed by the internal model logic on the basis of the ongoing battle.

Since organization boundaries of opposing forces need not line up, attrition calculations cannot simply be based on the relative capabilities of integral opposing units. For this reason, the concepts of "sector" and "subsector" are used. A sector is defined as that portion of the FEBA occupied by a basic combat unit (for Blue, the brigade; for Red, the division). As noted above, opposing sector boundaries need not line up. A subsector is defined as the portion of the FEBA between successive sector boundaries, regardless of side. Therefore, within a subsector, elements of a single basic unit face elements of only a single opposing unit. Where a sector is composed of more than one subsector, the elements of the basic unit occupying the sector are prorated among the subsectors in proportion to the number of minisectors in each of the subsectors. Ground interactions are assessed at the subsector level.

a. <u>User Inputs</u>

- Number of minisectors in the theater, and the locations of their boundaries in relation to a common reference line.
- Number of minisectors in each terrain band. There may be a maximum of 100 terrain bands in the theater.
- Locations of terrain interval boundaries within each terrain band, in relation to a common reference line. (This reference line is perpendicular to the reference line for minisector boundaries.) There may be as many as 50 intervals in each terrain band.
- The initial FEBA location in each minisector.
- Initial locations of organization boundaries for Blue and for Red. Each organization boundary must coincide with some minisector boundary.

- Minimum number of minisectors necessary to accommodate a division.

b. Inputs Generated by the Model

- Updated FEBA position.
- Updated locations of organizational boundaries. Boundaries may change as a result of commitment or retirement of units and as a result of combat interactions.

c. Outputs

- Compositions of opposing force elements in each subsector, for use in assessing ground interactions.
- Data on the terrain type or terrain features at each subsector where combat is to occur.
- Flank lengths and front-to-flank ratios.
- Number of minisectors in each subsector, for computation of personnel densities.

d. Assumptions

- Variations in terrain may adequately be represented by three classifications.
- It is adequate for theater level analysis to represent explicitly only a single type of terrain feature.
- Interactions which take place at locations other than the FEBA can be represented by the allocation of forces to protect organization flanks. Flank protection requires some fraction of the combat force. This fraction is not available for use along the FEBA and it may not inflict any casualties, but it does suffer casualties along with the rest of the subsector force.

2. IDAGAM

The theater is laterally divided into a variable number of geographic sectors, typically 10. Sector boundaries are perpendicular to the direction of FEBA movement. Sectors, which are assumed to be approximately the width of a corps, extend the length of the theater. Sectors need not be the same width, and the width of each sector may be varied as desired.

Each sector is divided front-to-rear into intervals. The interval boundaries are perpendicular to sector boundaries, and their locations are input as distances from a reference line. The intervals are used to play terrain-type variations, width-of-sector variations, defensive barriers and other geographical characteristics; therefore, each interval is a rectangle which is homogeneous with respect to these characteristics. The defender's posture is also input for each geographical interval; that is, for each side, the defender's response to an attack is determined by the geographic location of the combat. The response of Red to an attack in a given interval may be different from Blue's response to an attack.

Geographic sectors represent specific areas on the ground, remaining constant during a run of the model. However, the theater is also partitioned on a tactical basis. The portions of the geographic sectors in the vicinity of the FEBA are called "combat sectors;" all elements capable of participating in ground combat on a given day are located in them. Combat sector boundaries divide the forces of both opponents. Opposing ground forces interact only within combat sectors; there are no ground interactions across sector boundaries.

To the rear of the combat sectors, the theater is divided into a variable number of regions. The regions may encompass one or more sectors in width; they are usually at least two sectors wide. Each region boundary must coincide with a geographical sector boundary, but the region boundaries for Blue need not be at the same sector boundaries as Red region boundaries. Red and Blue need not have the same number of regions. Forces located in regions include combat units in reserve, air bases, supply installations, air defense weapons and administrative organizations. Appropriate elements in each region provide support for the forces located in the combat sectors in front of that region. Specific combat support and combat service

support activities are discussed under the applicable functional area.

There is one communications zone (COMMZ) for each side, located to the rear of the regions and away from all ground battle activity. Air bases, air defense weapons, and combat service support organizations are located here.

Except for one application, the depths of combat sectors, regions and the COMMZ are conceptual only. Specific distances from the FEBA to front and rear boundaries are not represented. The exception pertains to the operating ranges of aircraft and the distances from the FEBA of air bases in the regions and the COMMZ.

a. User Inputs

- Number of sectors in theater.
- Initial FEBA positions in each sector, in terms of distances from a common reference line.
- Locations of interval boundaries in each sector, in terms of distances from a common reference line.
- Data on terrain types, defensive barriers and other geographical characteristics for each interval in each sector.
- Sector widths, by interval.
- Blue and Red defensive postures when attacked; by interval.
- Number of regions for each side, and a designation of the geographical sectors which are in each region. Geographical sectors in the same region must be contiguous.
- Initial locations of force elements, by combat sector or region. When applicable, the conceptual distances of force elements from the FEBA are also input.

b. Inputs Generated by the Model

- Updated FEBA positions.
- Updated locations of force elements.

c. Outputs

- Force inventories, in geographical groupings required by other functional areas of the model.
- Data on terrain type, defensive barriers and other geographical characteristics where combat is to occur.
- The posture of the defending force in each sector in which an attack is to occur.
- Flank lengths and front-to-flank ratios.

d. Assumptions

- Ground combat occurs only within combat sectors. There are no ground interactions across sector boundaries.
- Ground combat may adequately be modeled at the theater level with resolution of forces and their activities at approximately corps level.
- Combat may adequately be represented without specifically considering maneuver, breakthroughs or the effects of a discontinuous FEBA.
- The interactions involving force elements not directly in contact with the enemy may adequately be modeled without representing the explicit locations of those elements.

3. LULEJIAN

The theater is laterally divided into as many as 10 sectors. Sector boundaries are perpendicular to the general direction of FEBA movement. Sectors, which are assumed to be approximately the width of a corps, extend the length of the theater. The sectors need not be the same width, and the width of each sector may be varied along its length as desired. Each sector is divided front-to-rear into as many as 15 intervals. The interval boundaries are perpendicular to sector boundaries, and their locations are input as distances from a reference line. Within each interval, the width of a sector remains constant, and there is a single type of terrain. As many as three types of terrain may be represented among the intervals.

Sector boundaries are identical for both opponents and divide the ground combat forces of both. Opposing ground forces interact only within sectors; there are no ground interactions across sector boundaries.

To the rear of the front-line forces, the theater may be laterally divided for certain operational purposes into two regions. The region boundary, which is the same for both sides, is the boundary between the highest numbered sector in region one and the lowest numbered sector in region two. The regions are significant in air operations, including those interacting with ground forces (air-to-ground, ground-to-air). They are also the conceptual locations of the supply depots which support the combat sectors directly forward of the regions. The regions have no significance with respect to the location or deployment of reserve, "fought-out," or replacement forces.

At a greater distance from the FEBA is a base of operations for each side. It is the width of the theater; its depth is represented only conceptually. Part of the conceptual lines of communication (represented as a single "stove-pipe" system) is located in this area, as is the single conceptual theater port for each side. Except for air interdiction along the length of the conceptual lines of communications, forces and installations within the theater base of operations are invulnerable to the enemy.

a. User Inputs

- Number of sectors in the theater. As the model is currently programmed, this may vary from one to ten.
- Initial FEBA positions in each sector, in terms of distances from a common reference line.
- Locations of interval boundaries in each sector, in terms of distances from a common reference line. There may be up to 15 intervals in each sector. Interval boundaries in a given sector need not be the same distance from the reference line as those in other sectors.

- Designation of which one of three allowable types of terrain is in each interval.
- Sector widths, by interval. Each interval is of uniform width front-to-rear.
- The highest numbered sector encompassed by air (and supply) region one. This and lower numbered sectors are in region one. Higher numbered sectors are in region two.
- Initial locations of force elements, by sector or region as applicable. A conceptual depth is associated with certain of the rear elements, but these are not explicitly input to the model.

b. Inputs Generated by the Model

- Updated FEBA positions.
- Updated locations of force elements.

c. Outputs

- Force inventories, in geographical groupings required by other functional areas of the model.
- Terrain types at locations where ground combat is to occur during each model time period.
- Sector widths, flank lengths and front-to-flank ratios.

d. Assumptions

- Classification of terrain in three notional types is adequate for theater-level analysis.
- There is no requirement to represent specifically either natural or man-made barriers or prominent terrain features.
- Ground combat occurs only within sectors. There are no ground interactions across sector boundaries.
- Ground combat may adequately be modeled at the theater level with resolution of forces and their activites at approximately corps level.
- Combat may adequately be represented without specifically considering maneuver, breakthroughs, or the effects of a discontinuous FEBA.
- The interactions involving elements which support maneuver battalions may adequately be modeled without representing the explicit locations of those elements.

4. VECTOR

The theater of operations is laterally divided into as many as 10 sectors. Sector boundaries are perpendicular to the general direction of movement of the FEBA. Sectors, which can be the width of one or more corps, extend from the rear of one force to the rear of its opponent. The sectors need not be of the same width, and the width of any given sector may be varied as desired. The sector boundaries are assumed to divide the forces of both opponents. Under certain circumstances, the elements of a force may be transferred among sectors. Opposing forces interact only within sectors; there is no interaction between forces across sector boundaries.

Each sector is divided front-to-rear into intervals. Interval boundaries, perpendicular to sector boundaries, occur where the width of the sector or type of terrain changes. Therefore, each interval is a rectangle with homogeneous terrain.

The sectors are further subdivided into lateral segments called battalion areas. The battalion areas are conceptual, in that their specific locations within a sector are not accounted for and they have no specific depth. They are considered to have a conceptual depth of about 3,000 meters on each side of the FEBA. The model keeps track of the number of battalion areas in a sector, and the forces of each opponent within them, but, since they do not have a location on the ground, such relationships as adjacency between battalion areas are not represented.

As the name implies, battalion areas are associated with task force groupings of approximately battalion size. As a convention, exactly one Blue battalion task force is associated with one battalion area. Fractional Red units may oppose Blue battalion task forces in battalion areas. The basic Red unit is typically a regiment. Battalion areas in a given sector which are exactly alike with respect to forces and terrain are grouped

for computational efficiency into battalion area classes.

In VECTOR-1, ground combat occurs in the battaion areas. Because the outcomes of combat in various battalion areas may differ, there is a specific FEBA position for each of the areas in a sector. These may be "smoothed" by the model to form a straight-line sector FEBA, but there is no requirement to do so. Similarly, the FEBA positions in each of the sectors may be smoothed to make the overall theater FEBA more nearly a straight line.

There is no explicit division of the theater in depth for either opponent. Conceptual distances from the FEBA are associated with certain force elements located in the rear, but those elements do not have a specific location in depth. The precision of the lateral location of all rear-area elements is to sector level only.

a. User Inputs

- Number of sectors in theater.
- Initial FEBA positions in each sector in terms of distance from a common reference line.
- Sector widths, by interval.
- Locations of interval boundaries in each sector in terms of distances from a common reference line.
- Force locations, by sector, and conceptual depth of certain forces, e.g., air defense weapons.
- Initial number of battalion areas in each sector.
- Initial locations of maneuver forces, by battalion area. (If desired by the user, tactical decision rules may be utilized to determine initial force dispositions.)
- Terrain classification with respect to trafficability and intervisibility for each interval in each sector. There are five trafficability classes and five intervisibility classes, for a total of 25 types of terrain.
- Location of obstacles and terrain features, e.g., rivers mountains and urban areas.

b. Inputs Generated by the Model

- Updated FEBA positions.
- Updated force locations, by sector.
- Updated locations of maneuver forces, by battalion area.

c. Outputs

- Force inventories, in geographical groupings required by other functional areas of the model.
- Terrain classification at the locations where ground combat is to occur during each model time period.
- Indication as to whether combat is occuring at an obstacle or terrain feature.
- Flank lengths and front-to-flank ratios.
- Inputs to this functional area are output to the user for reference.

d. Assumptions

- Ground combat occurs only within sectors. There are no ground interactions across sector boundaries.
- Maneuver unit combat occurs only within battalion areas, with no maneuver unit interactions across battalion area boundaries.
- Ground combat may adequately be represented without specifically considering maneuver, breakthroughs, or the effects of a discontinuous FEBA.
- The interactions involving force elements not directly in contact with the enemy may adequately be modeled without representing the explicit locations of those elements.

5. Discussion

In many respects, three of the four models are alike in their treatment of theater geography and the geographical organization of forces. Only CEM is significantly different from the others.

The geographical description of the theater is more detailed in CEM than in the other models. The theater may be divided into as many as 1,000 specifically identifiable minisectors. There may be as many as 100 different terrain bands laterally across the theater. This allows a significantly more detailed representation of the theater than is possible in the other models, which typically allow the theater to be divided into about 10 sectors. Although only three types of terrain can be represented in CEM, the large number of terrain bands, along with 50 possible changes of terrain within a band, allows a much more disaggregated description of terrain variations than is possible with the other models.

The divisions of the theater into a large number of minisectors in CEM permits great flexibility in representing the physical location of ground forces. It is this ability to keep track of the locations of forces, by unit, which is a primary strength of the model. The computation of the results of force interaction at the subsector level obviates the necessity for artificially making the boundaries of opposing forces line up across the FEBA. Also, the commitment and retirement of forces can be represented in detail.

There is little difference in the way IDAGAM, LULEJIAN, and VECTOR represent theater geography and deployment of forces. All employ sectors whose boundaries must be the same for both sides and there are no ground interactions across the sector boundaries. VECTOR is somewhat more detailed, in order that there be adequate information available for use in VECTOR's particular ground attrition calculations. Each battalion-sized unit conceptually has its own area of operations within a sector. The unit has no particular location within the sector, however, and adjacency between units cannot be considered. VECTOR allows terrain to be classified according to both intervisibility and trafficability. With five classifications for each of the two

terrain attributes, 25 distinct types of terrain can be represented.

The treatment of ground geometry is considered better in CEM than in the other models, with VECTOR the next best. There is little to choose between IDAGAM and LULEJIAN.

The representation of ground geometry in each of the models is essentially governed by the requirements of other functional areas, e.g., ground combat interactions, and is internally consistent. The capability in CEM to represent the specific locations of particular units is a worthwhile feature.

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B. COMMAND AND CONTROL

1. CEM

The model permits the user to simulate the function of command and control to a considerable level of detail. Periodically, at each echelon of command, an estimate of the situation is made, and based on this estimate, a mission is selected and fire support is allocated to subordinate commands. For the Blue side, this sequence of events begins at the theater level, to army, corps, division, and down to brigade level. For Red, the sequence is from theater, to army, to corps, to division. Since the Red force is not resolved below division level, questions concerning mission for each regiment, and the commitment or reconstitution of division reserves, do not arise.

For each time cycle or period, based on user input and model-generated data, the estimating and decision making of each echelon commander is done by the model. At theater level (time cycle 4 days), the commander makes three decisions each cycle based on the status of his own forces, without the benefit of estimates of enemy force strength. On the basis of the number of divisions per army, the theater commander can assign reinforcement artillery battalions to each army, as well as assign the number of CAS sorties to each army. In addition, he allocates supplies and personnel support to subordinate organizations. Allocations of various resources are discussed in other sections of this appendix, as are theater-level maintenance, transportation, and medical functions. These theater-level aspects of the model are not covered in this section.

At lower levels, below theater, the decisions made at the next higher level have a direct effect on each of the lower echelons. In addition, an estimate of the situation regarding enemy strength influences the commander's decision. The time period at each echelon is an integral multiple of the period at the next lower echelon. Currently, the periods

used are: theater, 4 days; army, 2 days; corps, 1 day; and division, 12 hours. At the beginning of each period, an estimate of the situation is made at the corresponding echelon which leads to mission selection, allocation of fire support, and commitment or reconstitution of reserves. When the beginnings of periods of more than one echelon coincide, the higher echelon decisions and allocations are treated first so that the lower echelons may act within the constraints of those decisions.

Estimates of the situation are made at levels below the theater level. They are made at the army, corps, and division levels, where a comparison is made of one's own actual strength to that of an estimated enemy. The strength of each side comprises the numbers of different types of maneuver and artillery battalions together with an assessment of their fighting capabilities. At army and corps levels, estimated force ratios are formed using full strength meeting engagement IFP's. These are used to determine estimated outcomes for possible missions. Estimated force ratios are also computed for estimated outcomes at division (Blue brigade) level, but in this case the IFP's for the mission being considered and the complementary mission of the opponent are used. The general rule for mission consideration is to strive for the most aggressive mission that is believed attainable in terms of the situation. Therefore, the order of mission consideration is: (1) attack, (2) defend, and (3) delay. In estimating the situation, each commander counts the actual strength of his battalions which are considered capable of the mission under consideration. When counting the opposing strength, he counts the strength of those estimated units that he considers capable of the mission which he estimates the opponent will undertake. This count of enemy battalions is an approximation based on what was opposing his sector in the recent past and on his intelligence capability (Section U, this appendix, "Intelligence"). An assessment of fighting capability of the counted battalions is than made to arrive at a comparative strength of the two sides.

A cycle of events takes place at each echelon once during each appropriate time period. The cycle consists of: estimate of the situation, decisions, engagement results, resource allocation, new estimate of the situation, etc. The theater cycle is unique in that it does not involve an estimate of the situation. It is limited to the decisions described above. The commanders at lower levels make the following decisions constrained by each higher echelon's decisions:

(1) Army Cycle. Within constraints of the theater allocations of new reinforcing divisions, and CAS, to field armies, the armies make mission decisions and fire support allocations to their subordinate corps each army cycle. Thus, each field army makes a mission selection and decides whether to retain or reconstitute a reserve by comparing an estimated friendly-to-enemy force ratio to input threshold values. An army that has selected a mission to defend or delay realigns its corps boundaries to frustrate the attacker's attempt to gain local superiority. Also, the army can shift corps artillery from one corps to another by combining artillery from all its subordinate corps and reallocating it among the corps at the beginning of each army cycle.

(2) Corps Cycle. The corps makes the same types of decisions as the army essentially the same way. Like the army, the corps makes a mission selection and decides whether to retain or reconstitute a reserve by comparing an estimated friendly-to-enemy force ratio to corps mission thresholds. A corps that has decided to defend or delay realigns its division boundaries in an attempt to frustrate the attacker's attempt to gain local superiority.

(3) Division Cycle. The division cycle represents the final decision level in the model. At the beginning of each division cycle, each brigade is characterized by its authorized status, its actual state, its present organization, and if

on-line, its sector boundaries. The division has received allocations of fire support from its corps. The division estimate of the situation is made, which leads to decisions regarding brigade missions, allocation of fire support to brigades, and commitment and/or reconstitution of the division reserve.

The division estimate is more detailed than that of higher echelons. For Blue, estimates and decisions are made for each subordinate brigade. Force ratios are formed and tested against threshold values to determine if the estimated outcome is win, draw, or lose. This is done for each mission which can be undertaken by the brigade, starting with the most aggressive. If not constrained by its own state, which reflects the brigade's actual condition as compared to that authorized, the first mission considered is attack. If the estimated result of the attack mission is not a loss, that mission is adopted. Various levels of artillery support and the commitment of the reserve are tested by forming appropriate force ratios and comparing them to the thresholds which define the estimated outcomes. The best possible estimated outcome, either win or draw, which is attainable with the various possible levels of combat power is found. Then the lowest level of combat power which can still attain that outcome is employed in the engagement.

If the estimated outcome of the attack mission under all possible conditions is a loss, the procedure described above is in turn applied for the defensive mission (with different thresholds describing engagement outcomes). If the defensive mission also always results in an estimated loss, then the delay mission is adopted.

At the user's option, threshold values of brigade state may be input to preclude the adoption of a mission which is considered too aggressive for the condition (personnel, weapons, and supplies) of the brigade. If the state value were below

the threshold for, say, an attack, then that mission would not be adopted, regardless of the values of the relevant force ratio.

Similar estimates are made for the Red side, but at the division level. Red units lower than division are not explicitly played in CEM.

After missions for each side are selected, and decisions are made regarding the level of combat power to be employed, the type of engagement to take place is determined. The determination of engagement types and engagement assessments are discussed in Section C of the Appendix, "Maneuver Unit Interactions," and FEBA movement is discussed in Section K.

a. Inputs by the User

- Initial quantities and compositions of forces for each side. For Blue, forces are described explicitly down to battalion level, and for Red, down to regiment. As many as 50 types of battalions and 50 types of regiments can be represented.
- Initial locations of forces, by minisector. Locations are specified for forces at each level of command down to Blue brigade and Red division.
- Threshold values of estimated force ratios which determine the estimated outcomes for attack, defend, and delay missions, respectively. Possible estimated outcomes are win, draw and lose. Separate threshold values are input for army, corps and division (Blue brigade) levels.
- Threshold levels for Red division and Blue brigade state values, below which those units cannot engage in attack missions regardless of estimated force ratios. Similar thresholds are input to determine if Blue brigades or Red divisions are capable of defending.
- Maximum number of minisectors which corps and division boundaries may be moved when boundary adjustments are being made for non-attack missions.

b. Inputs Generated by the Model

- Engagement results, including personnel casualties, materiel losses, and FEBA movement.

- Updated strength and status of each friendly unit, considering losses, replacements, and consumption and receipt of supplies.
- Estimated number of enemy units available for combat and their status (intelligence estimate).
- Updated FEBA location for each subsector.
- Total IFP values corresponding to the actual status of friendly units and values corresponding to the estimated status of enemy units. (IFP values which are input to this functional area are categorized as anti-armor, anti-light armor, and anti-personnel. They are combined within this functional area into a single, weighted IFP for each unit so that force ratios can be computed).
- Full strength IFP scores for each Blue brigade and Red division.
- Information as to whether a reserve is available for each organization at army, corps and (Blue only) division levels.

c. <u>Outputs</u>

- Designation of missions for each level of command down to Blue brigade and Red division.
- Updated locations of units, in terms of minisectors, and designation of the units to oppose each other in engagements.

d. <u>Assumptions</u>

- Estimates and decisions are made at each level of command on cycles of a fixed duration. The time length of the cycle for any command level having subordinate units is an integral multiple of the length of the subordinate's cycle.
- The theater commander makes decisions based only on the status of his own forces at each theater cycle.
- An estimate of the situation is made by each level of command below theater level. Each estimate, which is made once during the appropriate command cycle, is based upon friendly strength and an intelligence estimate of the enemy strength.
- Three decisions are made by the theater commander at the beginning of each theater cycle; these are based on the status of the commander's own forces:

(1) Assign reinforcing artillery battalions to armies in proportion to the number of divisions in each army.

(2) Assign CAS sorties to armies in proportion to the number of divisions per army.

(3) Allocate logistics resources down to corps level including supplies and personnel support.

- Army commanders make these decisions:

  (1) Assign reinforcing divisions.

  (2) Mission selection, based on estimated force ratios.

  (3) Reserve commitment or reconstitution.

  (4) Realignment of corps frontages (if army not attacking.)

  (5) Allocation of fire support to corps.

- Corps commanders make these decisions:

  (1) Mission selection.

  (2) Reserve commitment or reconstitution.

  (3) Realignment of division frontages (if corps not attacking.)

  (4) Allocation of fire support to divisions.

- Division commanders make these decisions:

  (1) Mission selection.

  (2) Reserve commitment or reconstitution.

  (3) Allocation of fire support to brigades.

- In considering missions, the most aggressive mission that is believed attainable in terms of the situation is considered first, i.e., attack, defend, delay, in that order.

- A comparative ratio of actual friendly strength to estimated opposing force strength determines force ratios used in estimates and mission selection. The estimates of opposing strength are based on strength observed in the recent past and on intelligence capability.

- All maneuver battalions are at the same state level as the parent brigade.

- Brigade state value determines whether the brigade is capable of attacking, defending, or delaying. If the

value is high enough it can do any one of the three; if less, it can defend or delay only; if still less, it can delay only.

- The actual mission of each brigade (or Red division) is selected by comparing estimated force ratios with input threshold values.

2. IDAGAM

The initial determination of force posture, and who the theater attacker will be, is provided by the user. For each succeeding day, the model computes two force ratios: one for enemy attack value vs friendly defend value, summed across all sectors; the other for friendly attack value vs enemy defend value. The side with the higher attack-against-defense force ratio is considered the theater attacker that day. The sectors of main attack for the theater attacker are defined next, either by user input or through model computations. If computed by the model, one sector per region is selected, which is the one with either the attacker's maximum penetration, or his minimum penetration, based on user input. For example, if the theater attacker was originally the theater defender, he selects a minimum penetration sector to push the enemy out of his territory before an attempt is made at deep penetration into enemy territory. Once the enemy is pushed beyond the original FEBA position in all sectors, the model will automatically begin to compute the sectors of main attack as the ones with the maximum penetration.

In addition to an overall theater attacker, the model designates a sector attacker for each sector. Further, the sector attackers need not all be on the same side as the theater attackers. The decision to attack in a given sector is made on the basis of comparison of the existing force ratios in the sector with input threshold values. Different threshold values may be applied, depending upon: (1) whether or not the sector has been designated by the user or the model as the sector of main

attack, if the theater attacker is making the decision; (2) whether the sector in question is adjacent to a sector which is being constrained by a front-to-flank ratio, and (3) the side (Blue or Red) making the decision.

The model logic is such that if one force attacks, then the opposing forces must defend or delay. If the theater attacker does not attack in a given sector, then the theater defender can choose to attack, or not attack based on a comparison of the existing force ratio with the appropriate threshold value. If neither side attacks, then a holding posture exists in the sector.

a. Inputs by User

- Designation of the theater attacker on the first combat day.
- Designation, for each side, of the sectors where the main attacks in the theater are to be made when the side in question is the theater attacker. This input is optional; if desired by the user, the model will select sectors of main attack.
- Designation of the criterion to be used by the model if the option for its selection of the sector of main attack is employed. The model will select one main attack sector in each region. This input determines whether it will be the sector with the attacker's maximum penetration or his minimum penetration. (If minimum penetration is selected it will apply only to a side which has lost territory since the start of combat. If all lost territory is regained, the model will automatically choose the sector of maximum penetration for that side.)
- Minimum force ratio for each side to attack in any sector, whether it is a sector of main attack or not. It is a function of whether the side in question is the theater attacker, and of the defensive posture which would be encountered.
- Minimum force ratio for each side to attack in a sector which is neither a sector of main attack nor adjacent to a sector constrained by front-to-flank ratio. It is a function of whether the side in question is the theater attacker, the defensive posture which would be encountered, and the particular sector involved. For

the sectors to which this minimum force ratio constraint applies, it is in addition to the constraint for all sectors, which is described immediately above.

b. Inputs Generated by the Model

- Ground and air values for attack and for defense, per sector and summed over all sectors, per side. These are used to generate the necessary force ratios. (The values are computed using the same method as selected for use in determining force values for the attrition calculations, e.g., antipotential potential.)
- The position of the FEBA, per sector, in relation to the original FEBA position. If the common reference line used to define location in the theater is different from the initial FEBA position, current FEBA positions are also given in relation to that line.
- For each side, the defensive posture associated with the current FEBA position in each sector.
- Designation of the sectors which are constrained by front-to-flank ratios.

c. Outputs

- Designation of theater attacker.
- Designation of the sectors of a main attack.
- Designation of the attacker, if any, in each sector, and the defensive posture of his opponent.
- Designation of the sectors, if any, where neither side is attacking.

d. Assumptions

- Each day the side with the greatest attack-against-defense force ratio is the theater attacker, except for the first day of combat. The theater attacker on the first day is specified by the user.
- When the option is chosen to have the model compute the sectors of main attack for the theater attacker, exactly one sector per region will be chosen. It will be the sector of maximum penetration, except for the case where the user specified that the sector of minimum penetration be chosen. If the sector of minimum penetration is specified, the theater attacker will make

that choice until all sectors are at least as far forward in the direction of movement of today's theater attacker as the original FEBA position. Subsequently, the sector of maximum penetration will automatically be selected by the model. The user may select the sectors of main attack directly. In that case this assumption does not apply.

- The decision to attack in each sector is determined by comparing with the input threshold values the attack-against-defense force ratios for each side. These threshold values may differ depending upon the side, whether the side in question is the theater attacker, whether the sector is a sector of main attack for the side in question, and the specific sector involved. There may be less stringent force ratio requirements to attack in a sector if it is a sector of main attack or if it is adjacent to a sector which is being constrained by front-to-flank ratio. In the process of determining a sector attacker, first choice is given to the theater attacker; only if he decides not to attack is the theater defender given the option of attacking.

3. LULEJIAN

The model uses decision rules which are fixed in the computer program to control the selection of offensive and defensive postures in each of the sectors. This set of calculations is made after results of each day's combat have been determined in order to define postures for the following day's battle.

Three basic postures for each side are represented in the model. These are: attack, hold (nominally a hasty defense), and delay. Combining these postures results in the following activities which are possible in each sector: Blue (Red) attack against Red (Blue) hold; Blue (Red) attack against Red (Blue) delay; and neither side attacking (i.e., both sides holding, resulting in a static sector). The postures in each sector for the initial day of combat may be input by the user, or approximately optimized among a limited set of user-specified choices. On subsequent days the selection of postures is governed by the logic which follows.

In determining daily postures, the current status of each sector is considered along with the effects of activity in adjacent sectors. Differing sets of rules are used to determine postures for a given day, based on whether an attack has occured in the sector on the previous day, and on the situation in the sector with respect to flank exposure. The five cases considered in choosing the set of rules are:

(1) One side attacks (previous day):

- Defender has two exposed flanks.
- Attacker has two exposed flanks.
- Each side has an exposed flank.

(2) Both sides defend (previous day):

- One side has two exposed flanks.
- Each side has an exposed flank.

A flank is considered to be exposed for a given side in a sector if the section of flank between the sector FEBA and the FEBA in the adjacent sector is shared with forces from the opposing side. The flanks on the extreme left and right sides of the theater are assumed to be of zero length and do not become exposed.

For each case, fixed decision rules are used to determine the postures in each sector. The posture decisions are based on: the relationship of the longest exposed flank to an input critical flank length; the success of the attack in the sector on the previous day, if applicable; whether the exposed flank lengths increased or decreased on the previous day; and the FEBA movement in adjacent sectors on the previous day. An attack is considered successful if the resulting FEBA movement in the sector is positive in the direction of the attack, or zero.

a. Inputs by User

- Designation of the theater attacker on the first combat day.
- Possible posture sets, by sector, to be evaluated by the model to determine approximately optimal posture and deployments in each sector for the theater attacker on the first combat day.
- If optimization of the theater attacker's first day deployments and postures is not desired, specific postures for each sector are directly input by the user.
- Threshold flank lengths for each side. If actual flank length is equal to or greater than the threshold value, the flank is considered critically exposed.

b. Inputs Generated by the Model

- The force postures on the first combat day, if the model's optimization technique is utilized.
- FEBA positions in each sector for each combat day and the movements of the FEBA during the previous combat day. The FEBA positions are given with respect to a common reference line.
- The results of attacks in each sector on the previous day as applicable.

c. Outputs

- Designation of theater attacker.
- Designation of the attacker, if any, in each sector, and the defensive posture of his opponent.
- Designation of the sectors, if any, where neither side is attacking.

d. Assumptions

- The postures of forces at sector (corps) level may adequately be categorized, for theater-level analysis, as attack, hold (defend), or delay.
- The factors controlling the choice of postures are those discussed in the general description: success of previous day's attack, number of flanks exposed, whether an exposed flank length is as great as some input critical value, and the previous day's FEBA movement in adjacent sectors.

- The degree of success of a side in a given sector tends to influence the success of that side in the adjacent sectors. That is, forward FEBA movement tends to "pull along" adjacent sectors, and rearward movement or lack of movement retards the forward movement of adjacent sectors. This assumption is embedded in the detailed rules for posture selection.

4. VECTOR

The model controls combat plans and activities through its tactical decision rule process. The tactical decision rule structure allows the user to specify the basic logic to be used by the model in making decisions, and to set the values and parameters upon which the decisions are based. Essentially, any variable or index in the model may be changed or set as a function of any other variable(s). The specific functional relationships are defined by the user.

Decisions may be made at several points during each day of the hypothetical campaign as modeled by VECTOR to allocate forces and supplies to sectors, move supplies, utilize reserves and replacements, and choose plans and activities by maneuver units. In particular, tactical decision rules 6 and 7 provide for the determination of the battalion area activity, taking into consideration the plans of opposing forces in the area. This rule is used for each battalion area class.

In conjunction with these rules, other rules are used to simulate additional aspects of command and control. For example, with appropriate inputs the user can simulate the effects of intelligence using rules 6 and 7. (See paragraph U of this appendix, "Intelligence.") Rule 5 allows the user to set a sector intention before the day's battle. The intentions of opposing forces at the sector level may in turn be given consideration when plans and activities are decided for battalion areas.

The model permits activities for the individual battalion area classes to be chosen from among 17 possibilities. These

are: Blue (Red) pursuit, Red (Blue) withdrawal; Blue (Red) advance, Red (Blue) delay; Blue (Red) attack, Red (Blue) defense; crossing or bypassing cities or a user-input terrain feature by either side; river crossings by either side; or relative inactivity (neither side attempting to move forward).

a. Input by User

- Tactical decision Rule 5 to determine a sector intention before the day's battle (not currently programmed in the sample decision rule package).
- Tactical decision Rule 6 and 7, to obtain the status of each battalion area class.
- Tactical decision Rule 6 and 7, to define the activity of each battalion area class.
- The composition of forces in each battalion area class, by sector (modified by the model for subsequent attrition and replacements).

b. Inputs Generated by the Model

- Status of weapons strength, current and prior day's, by battalion area class, by sector.
- Status of personnel strength, current and prior day's, by battalion area class, by sector.
- Any other model variable which the user wants considered in the decision processes.

c. Outputs

- Mission selection of combat units by battalion class, per sector.

d. Assumptions

- Tactical decision rules, as currently programmed or as written by the user, permit adequate simulation of command and control and establishment of postures.
- Resolution of decisions down to battalion level is appropriate in theater-level modeling.

5. Discussion

Of the four models, CEM and VECTOR are the most versatile in simulating command and control in the determination of combat posture. CEM uses detailed assessment procedures, consistent with those used to determine engagement results, to evaluate alternative courses of action in making estimates of the situation at various levels of command. In so doing, it takes into consideration more of the elements which are used in actual estimates than any of the other models, with the possible exception of VECTOR (discussed below).

The primary difference between a CEM estimate and an actual estimate of the situation is that, in the model, the missions of each command are selected by that command rather than by its superior. This is largely a matter of technique, however, since the higher command could use the same procedures if the estimate were made at that level. Provisions are made to simulate intelligence time lags by basing each commander's estimate of the current enemy situation on a weighted average of actual enemy situations in the recent past. In addition to mission selection, decisions regarding reserve formation and utilization, the boundaries of subordinate units, and allocation of fire support are based on the estimates of the situation.

Theoretically, the VECTOR model has virtually an unlimited potential capability to simulate command and control by means of user-devised tactical decision rules. The practical limitations are the time and resources available for the model user to formulate and program the rules. The model is structured so that decisions may be made at various points during the execution of each day's activities, and some of them may be dynamically dependent on the course of combat interactions as they occur. As with CEM, VECTOR permits enemy force estimates to be made on the basis of actual strengths in the past, rather than current actual strengths, to account for imperfect intelligence.

VECTOR also permits 17 force posture combinations, more than any of the other models.

The fixed program logic in IDAGAM does not provide for a detailed estimate of the situation as such, but the selections of theater and sector attackers are based on relative force ratios and the relationships of the force ratios to input threshold values. Defensive postures for a given side, however, depend solely on the geographic location of the FEBA in each sector. Degradation of knowledge concerning the enemy because of imperfect intelligence is not represented in the model. All force ratios are based on actual corresponding forces facing each other.

LULEJIAN also has fixed program logic which makes alteration of the decision rules relatively difficult for the user. The rules define the individual sector combat postures based on the degree of flank exposure, the criticalness of flank lengths and the success of prior attacks in the sector in question and those adjacent to it. The intelligence function is indirectly represented, in that some knowledge of the enemy is obtained by observing the results of past combat activities.

C. MANEUVER UNIT INTERACTIONS

1. CEM

The model uses firepower scores (also called IFPs - indexes of firepower potential) as the measure of the combat power of each weapon. These scores are used in the model to determine the results of combat interactions, including personnel and weapon system attrition and FEBA movement.

The firepower scores input to CEM represent directed firepower. Each weapon, as applicable, may have separate scores indicating specifically its potential to attrite armor (tanks), light armor (APCs) and personnel. Implicit in the scores for weapons capable of attriting more than one type of target are standard allocations of fire to these types.

The firepower values employed to determine combat outcome are dependent upon the type of engagement, the type of terrain, the supply status and the numbers and types of weapons.

Engagements of maneuver forces take place during the division cycle at the subsector level. A subsector is a segment of the FEBA on opposite sides of which are opposing elements of only one basic Blue or Red unit. (For Blue the basic unit is the brigade; for Red, the division.) The type of engagement depends on the missions chosen by the opposing units, and the type of position employed by the defender. The following table, extracted from the model documentation, shows the possible types of engagement and the circumstances in which they take place.

MISSIONS, TYPES OF POSITION, AND TYPES OF ENGAGEMENT

Red Mission / Blue mission	Red position type / Blue position type	Attack	Defend		Delay
		--	Prepared	Hasty	--
Attack	--	Meeting engagement	Blue attack of prepared position	Blue attack of hasty position	Blue advance
Defend	Prepared	Red attack of prepared position	Static	Static	Static
	Hasty	Red attack of hasty position	Static	Static	Static
Delay	--	Red advance	Static	Static	Static

Separate firepower scores for each firing weapon type against each target weapon category are input for each type of engagement.

Because engagements are at subsector rather than sector level, elements of a basic Blue or Red unit may be participating in more than one type of engagement. The fractions of each basic unit which are participating in particular engagements are proportional to the number of minisectors in each engagement subsector. For example, if a Blue unit is engaged in two subsectors, with 2 minisectors in the first subsector and 4 minisectors in the second subsector, one-third of the Blue unit is engaged in the first subsector and two-thirds in the second.

Each individual firepower score is modified by an input multiplicative factor to account for different types of terrain.

The factor is applied for each of the four types of terrain represented in the model; therefore, the user is not required to select a given type of terrain as "standard" for firepower scores of all weapons.

Supply constraints are represented by a reduction in consumption if available supplies are less than an input requirement. This causes a degradation in firepower which is linear between (1) the input supply requirement for full effectiveness, and (2) an input lower limit of degradation which corresponds to zero supply consumption.

The firepower scores applicable against given types of target weapons, e.g., anti-tank firepower scores (ATFP), are summed across all weapons having that capability, including supporting artillery and helicopters and CAS. The total score for forces in a subsector is then used to compute the attrition of opposing elements of the applicable target type. The total directed firepower scores, modified for terrain and supply considerations, are used in exponential equations to determine the attrition of each element of the opposing force. For example, tank attrition is computed as follows:

$$H_{Tn} = T_n \left[1 - e^{-K_n \frac{(ATFP)}{\Sigma T_m}} \right]$$

where:

H_{Tn} = the number of enemy tanks of type n that are damaged in an engagement.

T_n = the number of enemy tanks of type n in the engagement sub-sector.

ATFP = volume of friendly anti-tank firepower from all sources having an anti-tank capability, modified as described above.

K_n = "damage coefficient" of friendly anti-tank firepower against a tank of type n.

T_m = total number of all enemy tanks of all types in the subsector during the current division cycle.

The number of tanks destroyed is an input fraction of those damaged. Damaged tanks which are not destroyed may be eligible for retrieval and repair.

Attrition of light armor is analogous to that of tanks. Personnel attrition, however, is computed differently.

Two basic mechanisms are used to represent personnel attrition. For personnel associated with armor and light armor weapon systems, the user inputs the number of killed and wounded as a function of the type of vehicle damaged. Personnel, such as non-mechanized infantrymen, not associated with armor or light armor are accounted for in a "personnel pool." Casualties to the personnel pool are assessed using the following relationship:

$$Cp = M \left[1 - e^{\frac{-K(APFP)}{N_m}} \right]$$

where:

Cp = number of casualties to the personnel pool.

M = number of enemy personnel in the sub-sector that are not in vehicles.

APFP = volume of friendly anti-personnel firepower from all sources, modified as described above.

K = "personnel vulnerability" coefficient.

N_m = the number of minisectors in the subsector. (This value is used to allow consideration of personnel density in the calculations.) An input fraction of the personnel casualties are killed, and the remainder wounded.

Losses to ground-mounted anti-tank weapons and mortars are not assessed directly. Instead, an input fraction of each type of these weapons is destroyed for each percent of dismounted personnel in the subsector which become casualties. None of these damaged weapons can be salvaged or repaired.

The attrition mechanism in CEM relates firepower scores to attrition, but not in a fixed relationship. That is, greater friendly firepower scores cause greater enemy attrition, but the amount of attrition in a given situation is established by the user-input "k-factors." These factors are computed using accepted outcomes to some specific interaction in which the values of the CEM firepower parameters are known. This "benchmark" is chosen by the user, and may be based on historical data or on the results of more detailed simulations. A single known result for each CEM target type is necessary to establish the firepower vs. attrition curve applicable to it.

a. Inputs by User

- Number and types of weapons authorized for each maneuver unit.
- Firepower scores, by type of weapon, and type of engagement. Separate scores are input for the anti-tank, anti-light armor, and anti-personnel firepower of each weapon.
- "K-factors" to relate the total quantity of directed firepower to the attrition of the target types to which it is directed. These are used in the exponential attrition equations described above for maneuver unit calculations. Factors are input for attrition of personnel and of each type of armor and light armor.
- Factors to modify directed firepower scores on the basis of terrain, by type of firing weapon.
- Number of personnel casualties per armored weapon lost, e.g., tank, APC.
- Number of non-armored weapons lost, e.g., anti-tank weapons, mortars, for each percent of dismounted personnel casualties.

- Fraction of total personnel casualties which are killed and the fraction which are wounded. The remaining fraction of casualties are considered captured or missing.
- Fraction of damaged armored weapons which are destroyed.

b. Inputs Generated by the Model

- Updated inventories of weapons and personnel in each unit, for each division cycle.
- The number of target weapons, by type, present in each subsector, for each division cycle.
- Unit missions for each division cycle. These are used to determine the activities which take place in the subsectors.
- The location of each unit at the FEBA, in terms of the minisectors occupied.
- The terrain classification for each subsector. Four types of terrain are represented in the model.
- Factors to modify firepower scores to account for supply conservation caused by any existing shortages.

c. Outputs

- Number of personnel killed and number wounded.
- Number of weapons destroyed and damaged, by type.

d. Assumptions

- The basic capabilities of weapons may be expressed as three firepower scores, denoted as anti-tank firepower, anti-light armor firepower, and anti-personnel firepower. The values of the firepower scores are dependent upon which of seven types of engagement is taking place. The scores can be modified for each of four types of terrain represented in the model, and can be reduced to account for supply shortages. The use of firepower scores implies 3 significant additional assumptions:

  (1) Against a given type of target, e.g., tanks, the capability of a force is described by the total applicable firepower possessed by the force, i.e., the sum of its individual weapon firepower scores. The specific weapons mix and the consequent possible

effects of mutual support on total force capability are not considered. (The dynamic operation of the model can partially represent the effects of varying mixes of general weapon types, in that vulnerabilities of weapons to the opposing force may differ. Therefore, some weapons mixes may be more effective over time than others because of better survivability.)

(2) For weapons which are capable of attacking different general types of targets, the allocation of fire among those targets is assumed to be fixed. The use of the exponential equations causes the number of target weapons attrited to be dependent on the number available to be attacked. However, when targets of one general type become relatively scarce, there is no reallocation of fires to more numerous targets of another general type.

(3) The capability of a firing weapon averaged across all target weapons of a general type may be used as a measure of the specific capability of the firing weapon against each included target weapon. For example, the capability of a weapon against a specific type of tank is the same as the average capability of the weapon against all tank types. Alternatively stated, each general target type consists of a fixed mixture of specific target types.

- There is an exponential relationship between (1) the ratio of directed firepower scores to the relative target density, multiplied by a constant for each target type, and (2) the fraction of the targets attrited during each model time period. (The exponential relationship apparently is to account for such phenomena as overkill and the changes in acquisition rates incident to changes in the target population. It is not clear that this methodology is consistent with the assumptions used in generating firepower scores, e.g., a fixed expected expenditure of ammunition (EEA) with sufficient targets to make such an expenditure worthwhile.)
- Satisfactory values for the "k-factors" used in the exponential attrition equations can be determined from observed combat results or from lower-level simulations. Further, the values so obtained are applicable throughout the range of circumstances represented in the model. This assumption is required, since there is no known method for using more basic measurable weapons data to calculate the factors.
- The use of "k-factors" and the aggregation of forces at brigade or lower level (or the equivalent) is a satisfactory method to account for maneuver of forces.

- Combat takes place only across a linear FEBA perpendicular to the direction of movement. There are no interactions across unit flanks.
- Weapons engaging in combat are uniformly distributed across the front of the unit to which they belong.
- Attrition of anti-tank/mortar weapons is directly related to dismounted personnel attrition. An input fraction of such weapons is destroyed for each percent of dismounted personnel casualties.
- Fixed fractions of personnel casualties are killed and fixed fractions of damaged weapons are destroyed beyond repair. The fractions may be different for the two sides, and in the case of weapons, may vary by type.

2. IDAGAM

Maneuver unit interactions are modeled at the sector (typically corps) level. Inputs to the model are typically at division level, but force elements are summed and interact across an entire sector. Distribution of weapons is assumed to be uniform across a given sector. IDAGAM first calculates potential weapons losses, then offers alternative techniques to scale the total quantity of losses according to historical or judgmental attrition rates.

Potential losses are calculated using modified heterogeneous Lanchester square equations with discrete time steps of one model time period (typically, one day). The potential losses of personnel or a given weapon system during a single day are the sum of the losses caused by each weapon which fires at it. The rate at which a given weapon type can kill each opposing target type is input by the model user. For a given shooter-target combination during a single day, the number of targets killed is the product of the number of shooters, by type, times the input rate at which that shooter can kill the target in question. Allocations of the fraction of the fire of a given shooter type which will be directed against a specific target type are input. These allocations are based on the composition of some "standard" opposing force;

they are changed proportionately for forces with "non-standard" compositions. The input attrition rates may be varied as a function of the postures of the opposing forces, e.g., attack-defend, attack-delay.

When potential attritions by target and firer type are determined, the user has the option of accepting the calculated results, or scaling them in relation to historical or judgmental data by one of several schemes provided in the model. The most accepted means of scaling uses a concept of "antipotential potential". Values of each weapon are calculated based on the value (identically calculated) of all the opposing weapons which the firing weapon is potentially capable of killing during a given time period. The allocation scheme is specifically considered, so that a firing weapon derives no value from a capability to kill opposing weapons which are not present on a given day. The total value for each side in a sector is determined, and a "force ratio" is formed. This ratio is used as an entry argument for input tables of historical or judgmental data which give actual fractional value lost and FEBA movement. The potential attrition of weapons systems, as calculated from the modified Lanchester square equations, are then modified according to the value of each weapon destroyed, so that the total value of weapons lost is the same as that derived from the historical or judgmental data.

Forces may be degraded because of imbalance. Certain types of weapons may be required to have the protection of other types. When the number of protecting weapons is inadequate, then the weapons requiring protection are withdrawn for that time period. Withdrawn weapons can neither kill nor be killed. They are reintroduced into combat when they can be protected. When total attrition is determined for a sector, the losses are prorated among the divisions present in the sector.

a. Inputs by User

- Initial number of weapons present in each sector, by side and type of weapon. (This is input by type of unit and subsequently summed over all the units in a sector.)
- The number of weapons, by type, authorized for each type of division.
- The number of weapons in a "standard force", by side and type of weapon.
- The initial number of personnel present in each type of division.
- The number of personnel authorized for each type of division.
- The fraction of the fire of each weapon, by type and side, which would be allocated to each target weapon, by type, if the targets were part of a standard force. These allocations may differ between attack and defense.
- The potential number of each target weapon, by type, killed during a model time period by each firing weapon if the firing weapon allocated all its fire to that type of target weapon. This depends upon the type of firing weapon, the side to which it belongs, and the posture of the opposing force. It does not depend upon the number of targets of each type which are available.
- The number of casualties sustained when each type of weapon is killed, by type of killing weapon and by side. It may differ between attack and defense.
- The fraction of the weapons value lost per day, for each posture, as a piecewise linear function of the force ratio.
- Supply consumption rates for personnel and each type weapon.
- Initial supply inventories (only one type of supply is represented).
- A factor for effectiveness degradation caused by supply shortages. It is expressed as a piecewise linear function of the days of supply on hand.
- The effectiveness degradation of a division, by type, as a function of personnel shortage. The fractional effectiveness is input as a piecewise linear function of the fraction of authorized personnel strength which is present.

- The rate at which reorganization can reduce the degradation of effectiveness caused by personnel losses. Through reorganization, the fractional effectiveness may in time become as great as the remaining fraction of authorized personnel.
- Lists of weapons requiring protection and of weapons capable of providing it. These inputs are used to account for reduced effectiveness due to force imbalance.

b. Inputs Generated by the Model

- Updated inventories of weapons, by type, and of personnel.
- Potential ground weapon losses caused by the available sorties of CAS aircraft.
- The total weapons value for the available sorties of CAS aircraft, consistent with the particular ground value method being used.
- Updated supply inventories.
- Designation of attacker.
- Designation of posture.

c. Outputs

- Weapons losses, by type. The firing weapon type causing the loss is given.
- Personnel losses.
- Supplies consumed.
- FEBA movement (separately discussed).

d. Assumptions

- Assumptions are listed separately for two of the basic methods available in IDAGAM to compute attrition. Although other methods are possible, the two options covered are favored by the model developers and are representative of the available choices.

    (1) Assumptions for Antipotential Potential Scaling Method

    - Ground combat may be adequately modeled for theater-level analysis with forces aggregated

at the sector level.

- The relative ability of a specific type of weapon to kill a specific type of enemy weapon may be represented by an input attrition rate. The rate is expressed as the potential number of target weapons killed per day, given that the firer allocates all fires to that target. It depends upon which side the firer is on, whether he is attacking or defending, and the posture of the defending force. The rates are used in the model in conjunction with allocations of fire which may vary according to the number of target weapons of a specific type which are available. "Potential" attrition is thus computed. The average effects of such variables as maneuver, terrain, visibility and range-to-target are implicit in the attrition rates.

- The fractional value of a force which is actually attrited during a model time period is a function of the force ratio. Total force values and force ratios are computed using the antipotential potential method. The numbers of potential weapons losses are proportionately adjusted so that the sum of their values is the same as the value loss determined by means of the force ratio. The functional relationship between value attrited and force ratio is input by the model user; no particular relationship is assumed within the model.

- The basic assumption underlying the use of a scaling technique is that, although relative attrition in a theater-level model may be modeled on a weapon-by-weapon basis, total attrition may not be. Some other, overall relationship must be used to account for complexities in force interactions which are not modeled. In IDAGAM, this overall relationship is based upon the force ratio.

- The effects of imbalances in force composition may be represented by requiring that certain types of weapons be protected by other types. Unprotected weapons do not participate in combat.

- All units in a given sector sustain the same fractional losses of weapons and personnel.

(2) <u>Assumption for the Non-Scaling Method</u>

- Ground combat may be adequately modeled for

theater-level analysis with forces aggregated at the sector level.

- The ability of a specific type of weapon to kill a specific type of enemy weapon may be represented by an input attrition rate. The rate depends upon the side of the firing weapon, whether it is attacking or defending, and the posture of the defending force. The rates are used in the model in conjunction with allocations of fire which may vary according to the number of target weapons of a specific type which are available. The average effects of such variables as maneuver, terrain, visibility and range-to-target are implicit in the attrition rates.
- Attrition rates are not affected by supply shortages.
- Changes in allocation of fires are proportional to the differences between the composition of the target force and the composition of a user-specified standard force.
- All units in a given sector sustain the same fractional losses of weapons and personnel.
- The effects of imbalances in force composition may be represented by requiring that certain types of weapons be protected by other types. Unprotected weapons do not participate in combat.
- The reduction of overall unit effectiveness due to weapons losses is completely reflected by the reduction in the number of weapons available for employment. Personnel casualties, as such, do not affect unit effectiveness.

3. LULEJIAN

The maneuver unit interactions methodology manages attrition by trading space for survivability. For both sides, there is a direct relationship between attrition and FEBA movement. The rate of attrition is influenced by the separation distances between opposing force elements, as is the capability of forces to locate each other to the degree necessary for the employment of maneuver unit weapons. Also, the fraction of available

forces which is committed to the front lines during each combat day depends upon actual FEBA movement. Because of these interdependencies, an iterative process is used to determine maneuver unit commitment, acquisition, attrition and FEBA movement. Appropriate trial values for separation distances and FEBA movement are input by the user and computations using subsequently modified values are continued until convergence is achieved.

Before forces become vulnerable to the fires of opponents, they must be "localized" by means of the model's acquisition processes. Specifically, the locations of individual infantry formations, such as squads, must be known, and individual tanks and APCs must be located. When elements are localized, attrition is assessed using exponential equations which consider the number of firers, the number of targets, and weapons effectiveness potentials.

Three types of maneuver units are represented; with notional weapons, they are:

Bn Type	Weapon
Infantry	Riflemen, 3 types of mortars, and 3 types of anti-tank weapons
Mechanized Infantry	Riflemen, 3 types of APCs, 3 types of anti-tank weapons, and 3 types of mortars
Tank	Three types of tanks and 3 types of mortars

Within each battalion type, attrition is assessed directly only for certain elements. In infantry battalions these are riflemen; in tank battalions, tanks; and in mechanized infantry battalions, riflemen and APCs. Losses of other weapons are calculated proportionately to those whose losses are directly computed. Omitting the effects of mortars, which

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are considered fire support weapons, the possible firer-target combinations are as follows:

FIRER	TARGETS
Tanks	Riflemen, Tanks, APCs
Riflemen	Riflemen
Anti-tank Weapons	Tanks, APCs
APCs	Riflemen, Tanks, APCs

Although force compositions are input to the model and accounted for at the battalion level, weapons interaction equations are applied at the sector (corps) level. Also, the effectiveness values of the various types of generic weapon systems, such as tanks, are input separately, but these values are subsequently averaged across all the types. The attrition equations then treat these averages as the effectiveness values of a single average generic system, e.g., tanks.

Interactions occur in the following force posture combinations:

Attack - Defend

Attack - Delay

Hold - Hold (Inaction)

Only the values of the acceptable attrition thresholds distinguish the defend posture from that of delay; there can be more willingness to relinquish territory and less willingness to incur casualties for the delay posture than for defend. When neither side attacks (hold-hold) no FEBA movement occurs and there is no attrition to either side.

a. Inputs by the User

- Nominal anti-personnel (rifleman), anti-tank and anti-APC potentials for maneuver unit weapons, by type, at specified ranges.

- Coefficients for the function which transforms nominal weapons effectiveness potentials into potentials at specific ranges.
- Trial average separation distances between opposing elements for the initial step in the iterative process to determine attrition and FEBA movement. (Subsequent separation distances are computed within the model.)

b. Inputs Generated by the Model

- Numbers of riflemen, tanks, and APCs which have been located to the accuracy necessary to be vulnerable to opposing maneuver unit weapons.
- Maximum acceptable (threshold) attrition rates, by posture and element being attrited, as modified because of unit histories.
- Maximum (unopposed) FEBA movement rates.
- Average separation distances, for other than the initial iterative step.
- Personnel and weapons losses caused by supporting fires and CAS.

c. Outputs

- Separation distances (used to test for convergence of iterative computation).
- Attrition of personnel and weapons.
- FEBA movement.

d. Assumptions

- Each side has the capability to manage attrition rates of tanks, personnel and APCs by making decisions regarding the amount of territory controlled.
- The fraction of the mortars and anti-tank weapons attrited in infantry and mechanized infantry battalions is equal to the computed fraction of infantrymen which are attrited. In tank battalions, the fraction of anti-tank weapons lost is equal to the fraction of tanks lost.
- Infantrymen are vulnerable to opposing maneuver unit weapons, other than mortars, only after individual infantry formations, e.g., squads, have been located.

- Tanks and APCs are vulnerable when individually located.
- The effectiveness of maneuver unit weapons can be expressed as a function of range in the following form:

$$\text{EFFECTIVENESS POTENTIAL} = C_o + C_1/\text{RANGE},$$

where C_o and C_1 are constants input by the user.

- The attrition of specific force elements in a given sector (corps area) can be computed using equations of the following form:

$$\text{FRACTION OF ELEMENTS ATTRITED} = 1 - e^{-\frac{\text{TOTAL ENEMY POTENTIAL TO ATTRITE THE ELEMENTS}}{\text{NUMBER OF VULNERABLE ELEMENTS}}}$$

- For each primary force element (tanks, APCs, infantrymen) there are direct relationships between attrition and FEBA movement, in the following forms:

- For the attacker,

$$\frac{\text{ACTUAL FEBA MOVEMENT}}{\text{MAXIMUM (UNOPPOSED) FEBA MOVEMENT}} = 1 - \frac{\text{ACTUAL ATTRITION}}{\text{MAXIMUM ACCEPTABLE ATTRITION}}$$

and for the defender,

$$\frac{\text{ACTUAL FEBA MOVEMENT}}{\text{MAXIMUM (UNOPPOSED) FEBA MOVEMENT}} = \frac{\text{ACTUAL ATTRITION}}{\text{MAXIMUM ACCEPTABLE ATTRITION}} - 1$$

4. VECTOR

Maneuver unit interactions are modeled at the battalion task force or equivalent level. Two basic techniques are used for these interactions. When an individual battalion task force of either side is engaged in an attack upon a defensive position of his opponent ("assault activity") a detailed dynamic submodel is used to determine results. For any other activity, e.g., attack versus delay or neither side attacking, the results are obtained by the model from user-supplied tables. Therefore, once the decision is made to engage in other than the assault activity, the resulting attrition of weapons and personnel and the movement of the FEBA do not depend upon the specific

situation which exists nor the strengths of the forces involved. Tactical decision rules are used to determine activities, and any aspect of the existing situation in a battalion area can be considered in making the determination. Only in this way do force strengths and capabilities influence the results of non-assault activities. The non-assault activities represented in VECTOR-1 for both Blue and Red forces are as follows:

Advance versus delay
Pursuit versus withdrawal
Relative inaction (neither side attempts to advance)
Passage through an urban area
Bypass of an urban area
River crossing operations
Passage through a user-defined terrain feature
Bypassing a user-defined terrain feature

The tactics and relative strengths of the opponents must be considered by the user in preparing the input tables of results of the non-assault activities.

When the tactical decision rules determine that an assault activity is to take place in a battalion area, a detailed model of maneuver unit interactions, a "dynamic submodel", is used to assess attrition. The attrition process is based upon the following basic differential equation of combat:

$$\frac{dn_i}{dt} = -\sum_j A_{ji} N_j$$

which is approximated in the dynamic submodel by

$$\Delta n_i = \sum_j A_{ji} N_j \Delta t$$

where Δn_i = the change in the number of target weapons of type i during small time increment Δt,

N_j = number of type j firing weapons present at the beginning of the increment

A_{ji} = the attrition coefficient describing the capability of weapons of type j to kill weapons of type i

The attrition coefficients, A_{ji}, do not remain constant throughout an engagement. They are recomputed for each discreet time interval, Δt. The number of target weapons of type i is used for each computation of A_{ji}; therefore, the equation used in the model is an approximation of neither the Lanchester Square Law nor the Lanchester Linear Law, as those laws are usually presented.

Nine notional weapons along with personnel are represented in the dynamic submodel of the assault activity. These may be organized in up to 10 notional types of battalion task forces for the Blue side. Ten types of organizations of similar size, for example, regimental task forces, are possible on the Red side. Each maneuver unit interaction involves exactly one Blue battalion task force; it may be opposed by a fraction of a Red task force. The fraction of a Red task force opposing a Blue task force may be less than or greater than 1.

Combat is represented by the advance of the attacking force toward a fixed position of the defending force. Eight scenarios may be input by the user to describe the advance. Elements of the input scenario are: distance from the objective to each attacking weapon at the start of the attack; the relationship of the nominal speed of attacking weapons types to their velocity component in the direction of the defender; the fraction of the time that an attacking weapon type is moving; the weapon types which are mounted on APCs, and the distance from the objective at which each attacking weapon stops and remains stationary, when applicable. In addition, the overall speed of the attack can be varied according to the trafficability of the terrain.

At each time/range step during the assault, the numbers of weapons involved in the combat are updated, and the attrition

coefficients, A_{ji}, are recomputed. Attrition is assessed, and the tactical rules are used to determine the actions the forces take based on the results of the combat up to that time. Tactical air, artillery or helicopter support may be requested. The effects of such support are calculated, and the resulting change in the status of the forces is reflected for subsequent time/range steps. Tactical decision rules are also used at each step to determine if either force withdraws from the engagement. If the defender withdraws, the FEBA is moved a distance specified by the user input. If the attacker breaks off the attack, the defender retains his position and there is no FEBA movement. If the attacker overruns the defender, then the defender is presumed to withdraw. After either side breaks off the engagement, no further attrition is assessed.

Data describing the environment and the weapon systems characteristics are used at each time step to compute the attrition coefficients. The two major factors which are considered for each firer-target combination are (1) selection and acquisition of targets and (2) the rate at which the firer can kill targets which have been engaged. The nature of the data which are used in the calculations is given below in the inputs section.

a. <u>Inputs by the User</u>

- Tables of attrition and FEBA movement resulting from non-assault activities. (These input tables fully describe the outcome of non-assault activities; the remaining user inputs are for use by the dynamic submodel in computing results of assault activities.)
- Scenario data.
- Terrain trafficability and intervisibility indexes. There may be 5 categories of each for a total of 25 terrain classes.
- Range step size used in storing range-dependent data. It may be different for each weapon type.

- Pinpoint and non-pinpoint target acquisition rates. The pinpoint acquisition rates are input as a function of the observed weapon type, but may be modified to account for observer type and range. The non-pinpoint acquisition rates are indexed according to range, the observing weapon type, and whether the target is moving or stationary; they may be adjusted to account for the type of weapon being observed. Both rates may be corrected to account for observer motion.
- Priorities of target selection for each firer.
- Kill rates, indexed according to range, the firer-target combination, and whether either the firer or target is moving. It is defined as the inverse of the mean time to kill. (Given that the firer-target pair is isolated from the rest of the engagement, the kill rate is the reciprocal of the mean time required for the firer to kill a target, given that the firer and target survive until a kill is achieved. Under the described circumstance, the target can be regarded as passive.) Kill rates are calculated using basic weapons data such as probabilities of hit and kill, mean times to fire, and mean projectile flight times.
- The effects of an artillery round against targets in the battalion area, indexed according to target type and activity. The data are for an "average" round; therefore, considerations of allocation of fires among targets, impact point dispersions and target geometry must be made outside the model and reflected in the input data.
- The number of artillery rounds to be fired, regardless of the number of tubes present, for specified missions, e.g., preparation or calls for fire at a breakpoint.
- The number of personnel lost for each type of weapon destroyed.

b. <u>Inputs Generated by the Model</u>

- Designation of the activity for each battalion area.
- Force deployments, organizations, and strengths.
- Decisions to call for artillery fire and close air support.
- Decision by the attacker or defender to break off the engagement.
- Number and effectiveness of CAS sorties to attack in each battalion area.

c. Outputs

- The identification of the winner and loser in each engagement.
- Losses of weapons and personnel. The weapon which inflicted each loss is identified.
- Expenditures and combat losses of ammunition, by type, and of general supplies.

d. Assumptions

- The differential equation of combat and its approximation (given above) as used in the dynamic submodel are accurate representations of battalion-level attrition processes.
- The assumptions and derivations used in transforming basic environmental and weapon performance data into the attrition coefficients, A_{ii} are valid. (These assumptions and deriviations are available in the model documentation; they are not included in this report because of their length and complexity.)
- The employment of battalion level forces in an attack may adequately be described by the scenario elements listed above in the general discussion.
- The outcome of non-assault activities at battalion level is unaffected by the specific condition of the opposing forces, once the decision to engage in the activity has been made. The condition of the opposing forces may be considered in arriving at the decision.
- There is a fixed, average allocation of artillery fires which is not affected by the specific situation at the time the fires are delivered. Average target distributions and densities are similarly fixed.
- Rates of fire of maneuver unit weapons are unaffected by ammunition supply levels.
- Within the model, the volume of artillery fire is not dependent upon the number of tubes available. Considerations of tube availability may be reflected in input data for volumes of fire.

5. Discussion

a. Forms of Ground Attrition Equations

Each of the models uses a different mechanism to compute

attrition of maneuver unit elements. These mechanisms are explained above in the sections describing the individual models. The basic mathematical formulations used are to varying degrees traceable to assumptions regarding the nature of combat interactions. Some of them are supported by rigorous derivations, set forth mostly in papers separate from the model documentation. For others, no rigorous derivations could be found. Even when derivations have been made, however, they have usually been after-the-fact attempts to gain understanding of forms, e.g., Lanchester linear and square laws, which have been in use over a period of time. Further, the forms accept the validity of using expected values of random variables which are extremely difficult to measure, if in fact they are measurable at all. Because all four of the models are deterministic, none of them can account for the particular probability distributions of required input values and their effect on outcomes. Also, all of the attrition forms used in the models are simplified approximations of reality, in that there is currently no way to quantify scientifically or to use in a computer simulation all the variables which are important to the outcome of theater combat. Because of these considerations regarding the current state of the art, rigorous derivations for basic attrition relationships were not given overriding importance in this study. Intuitively plausible attrition forms were considered satisfactory, whether or not rigorous mathematical derivations existed for them. (This is not to state that further research into basic mathematical representation of combat processes is not of extreme importance in the modeling field.)

b. Weapons Aggregation

The capability of a theater-level model to represent the performance and attrition of maneuver unit weapons in a relatively disaggregated way is considered of major importance. Disaggregation assists the analyst in interpreting the overall

results of model simulations used for any purpose, and is necessary for evaluation of the effects at the theater level of weapon systems tradeoffs. VECTOR and IDAGAM employ significantly less aggregation of maneuver unit weapons than do LULEJIAN and particularly, CEM.

In the VECTOR dynamic submodel of an attack on a hasty defense, all attrition calculations are made on the basis of specific shooter-target pairs. For each type of weapon represented, information pertaining to the capability of the weapon to acquire and destroy each type of target is input by the user and is not further aggregated during attrition calculations. The inputs are in the form of basic weapons performance data, as a function of posture and environmental conditions. The allocation of fires of each type of weapon to specific types of targets is dynamically calculated, based on acquisition capabilities and input priorities. Up to nine types of maneuver unit weapons can be represented for each side.

The IDAGAM model also performs attrition calculations using input capabilities of each type of weapon against each type of opposing weapon. The input capabilities are more aggregated than in the VECTOR model, in that they describe the potential number of each type of target weapon destroyed by each firing weapon during a model time period (typically, one day). That is, the inputs are coefficients for heterogeneous Lanchester square equations. Also, the allocation of fires of each type of firer to each type of target in some standard force is input by the user. The allocations are modified by the model in proportion to the difference between the composition of the actual target force and the standard force. No aggregation of weapon types takes place during attrition calculations. Because the IDAGAM model can be redimensioned relatively easily by the user, there is no fixed maximum number of types of weapons which can be represented. Typical limits are 10 to 12 types.

Attrition calculations in IDAGAM and VECTOR are made for each shooter-target pair. Therefore, it is possible to attribute each weapon loss to the type of opposing weapon which attrited it. Shooter-target "scoreboards" are available in the output of both models.

The maximum number of types of maneuver unit weapons, including riflemen, which can be represented in the LULEJIAN model is 13, comparable to VECTOR and IDAGAM. Although capabilities are input for each weapon type, the model aggregates weapons into groups when computing attrition. For example, the three types of tanks are aggregated into a single average tank type. The number of each specific weapon type within a group which is considered attrited is proportional to the number of that type in the group. Similar linear disaggregations are made to determine the type of weapon which inflicts attrition. The LULEJIAN model also differs from IDAGAM and VECTOR in that attrition is directly computed for only three generic types of maneuver unit weapons: tanks, APCs, and personnel. The other weapons, such as anti-tank weapons, are attrited in proportion to the losses in one of the three generic types.

The CEM model uses sums of anti-tank, anti-light armor, and anti-personnel firepower scores to determine attrition. Therefore, the identity of the firing weapon is lost when its particular firepower score is added to the scores of the other weapons. In contrast, the identity of each type of weapon is retained with respect to vulnerability. For example, the total opposing anti-tank firepower score is used to compute the attrition of each type of tank, but a different "k-factor," vulnerability coefficient may be associated with each type. For a given opposing score, the loss rates for different types of weapons need not be the same. CEM represents 12 types of tanks, 12 types of APCs, 5 types of helicopter, 12 types of anti-tank and mortar weapons, one type of personnel dismounted

from tanks and APCs, 8 types of artillery tubes, and one type of artillery battalion personnel. Other maneuver unit weapons, such as individual small arms are not discreetly represented. Maneuver unit firepower contributed by individual weapons is attributed in the model on a per-capita basis to the non-armor personnel in each type of maneuver unit. Attrition of individual weapons is directly proportional to the personnel losses, and the firepower contributed by them is reduced accordingly.

The VECTOR model is considered superior to the other models in its ability to represent maneuver unit weapon systems discreetly. The other models, in order, are IDAGAM, LULEJIAN and CEM.

c. Force Aggregation

The attrition calculations in IDAGAM and LULEJIAN are made at the sector level, with opposing forces of approximately corps size. Computations in CEM and VECTOR are made at a much lower level, with opposing units of brigade size or smaller.

For IDAGAM and LULEJIAN, the assumption of force homogeneity across an entire corps sector is obviously only an approximate representation of reality. This approximation can be made more accurate, however, by the use of input parameters that account for activities within the corps which are not explicitly represented in the theater-level models. Lower level, higher resolution models can be used to generate theater-model inputs which reflect activities of units below corps level.

The VECTOR model computes attrition at the battalion level or its equivalent. This allows a more explicit representation of lower level interactions than is possible with IDAGAM or LULEJIAN. In VECTOR, however, the relationships between combat results computed at battalion level and the consequent results at theater-level must be defined in the model. This is accomplished by the model user through the tactical decision rules.

CEM is similar to VECTOR in that engagement results are computed at brigade (or the equivalent) level or lower. However, in CEM, the extrapolation of results to theater-level is accomplished through fixed internal model logic. Fixed extrapolation logic makes CEM easier to use than VECTOR, but allows less flexibility. The use of aggregated firepower scores in CEM limits the capability of the model to represent explicit combat processes, even though assessments are made at a low level.

Results of theater-level analysis may be valid whether the interactions are modeled at relatively high or low levels. For higher levels, such as corps, care must be taken to insure that the inputs properly consider the effects of lower level interactions which are not specifically modeled. For lower levels, similar care must be taken that the assumptions implicit in the extrapolation of results from low level to theater level are consistent with the overall assumptions for the analysis being conducted.

Because the processes are more explicit within the model, and important assumptions are less fixed and "hidden" in input data, lower level interactions are judged preferable. Therefore, from the standpoint of force aggregation, VECTOR is considered superior, with CEM next, and IDAGAM and LULEJIAN about the same.

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D. ORGANIZATION OF THEATER AIR FORCES

1. Topic

This section discusses the organization of the theater air forces into various aggregated aircraft groupings and the basing of these groups. The type of missions modeled and the manner of allocating aircraft to missions is discussed.

2. CEM

Aircraft are of only two types, attack and fighter. Once each day CEM apportions all attack aircraft to one of three roles based on input allocation goals. Depending on input thresholds of success, allocations between the missions are varied each day. Aircraft on the ground may be in sanctuary (rear air base) or non-sanctuary (forward air base). There is no subdivision of air space.

a. Inputs By User

- Number of aircraft by type (attack and fighter) by base (two bases per side).
- Effective sortie rate, by aircraft type.
- Percentage allocation of attack aircraft to Combat Air Support (CAS), Counter-Air (CA), and Interdiction (INT).
- A percentage allocation of Counter-Air and Interdiction missions to escort missions.
- Attrition thresholds for Counter-Air missions, Interdiction missions and Air Base ground losses.
- Maximum and minimum CA, CAS and INT allocations.
- Theater arrivals by time, type and location.

b. Inputs Generated by the Model

- Previous aircraft losses.
- Breakdown of CAS missions to divisions.

c. Outputs

- Number of missions flown by mission type per day.

d. Assumptions

- One aircraft with a sortie rate of two is equivalent to two aircraft with sortie rates of one.
- Aircraft interact on a single, theater-wide basis. Identical air support is available to all parts of the theater.
- Aircraft are completely notionalized into two types (fighter and attack) and six missions (close air support, interdiction, air base attack, escort, suppression, and intercept).
- Logistics do not constrain the air effort.

3. IDAGAM

Once each day, IDAGAM performs a calculation to determine the aircraft missions which are flown. Except for the logical procedures for the assignment of CAS strikes to particular sectors and for determining the number of suppression aircraft, the procedure is of an accounting nature and is independent of what is occurring in the remainder of the model. The model contains logic to reassign aircraft which are assigned to impossible missions by input. The external inputs, the data drawn from the model and the outputs are listed below.

a. Inputs by User

- Number of regions (currently two for Blue, three for Red).
- Distances from FEBA to one forward and one rear base in each region.
- Distance from FEBA to COMMZ air base.
- Aircraft by type at each air base (currently 10 types).
- Range restrictions by aircraft type.
- Payload degradation factors by aircraft type by location.
- Sortie rates by aircraft type, by type misson.

- Allocation percentage to seven basic missions by aircraft type.
- Percentage suballocation to four suppression missions and supply interdiction.
- Aircraft arrivals by time, type, and location.

b. Inputs Generated by the Model

- Previous aircraft losses.
- Infeasible assignments.
- Sector priorities to receive CAS.

c. Outputs

- Number of sorties, by aircraft type, by mission, by base, flown each day.
- Number of aircraft by type at each air base each day.

d. Assumptions

- Two aircraft with a sortie rate of one each are equivalent to one aircraft with a sortie rate of two.
- Aircraft interact on a regional basis. Aircraft fly across regional lateral boundaries on the basis of input percentages.
- Aircraft are launched at uniform intervals.
- Initial daily launches for Red and Blue are simultaneous.
- Except for the allocation to suppression, all aircraft mission allocations are fixed based on user input and therefore are independent of the course of the battle.
- A linear degradation of sorties occurs when supply shortages exist.

4. LULEJIAN

The LULEJIAN model employs a game theoretic technique to generate a specific allocation of aircraft to missions. The user specifies one of four preference levels for the assignment of aircraft types among missions. The model then uses these

preferences in conjunction with a model-selected ordering of missions so as to develop the specific, theoretically "good" assignments, "good" being defined as the assignment which provides an approximately enforceable outcome for either side based currently on area gained or lost on the ground. The calculated allocations are identically applied to the aircraft inventories in each of two regions per side. Suballocations to provide escort and suppression support and to intercept aircraft on particular mission are made linearly, based on the numbers of sorties flown on the principal mission. Suballocation of CAS to sorties is linearly apportioned based on total maneuver units in sector. Linear degradation of effectiveness due to shortage of general aviation supply is possible.

a. <u>Inputs by User</u>

- Initial aircraft inventories, by type, by region.
- Aircraft assignment preference, by aircraft type, by mission.
- Sortie rates, by aircraft type, by mission.
- Mission priority options (currently 18 possibilities).
- Supply requirement, by aircraft sortie type.
- Aircraft arrivals.
- Effectiveness of interdiction strikes.[1]

b. <u>Inputs Generated by the Model</u>

- Previous aircraft losses.
- Mission priority selection.
- Allocations.
- Total battalions currently in sectors.

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[1]Suballocation of interdiction sorties to specific types of interdiction appears to use a simplified logic which is reasonable only if interdiction is destroying a large (> 50 percent) proportion of all targets. At low levels (< 20 percent) the procedure generates a poor allocation.

c. Outputs

- Number of sorties by aircraft type, by mission.

d. Assumptions

- One aircraft with a sortie rate of two is equivalent to two aircraft with sortie rates of one.
- That the approximate optimization technique finds a "good" allocation.
- A linear degradation of sorties occurs when supply shortages exist.
- CAS missions are required in proportion to total population of ground forces in each sector.

5. VECTOR

The VECTOR air model is organized on a sector (corps) basis. Seven aircraft types are assigned daily to the intercept mission, seven attack missions, and escort missions corresponding to each attack mission. Attackers with their escorts fly in groups sized by input. Differences in range, loading and basing are input by means of varying the types of aircraft in a given sector. Air forces in one sector are essentially independent, on a daily basis, of air forces in other sectors. The logic for allocations is input as a tactical decision rule routine. (The model, per se, does not make allocation decisions.)

a. Inputs by User

- Number of aircraft, by type.
- Aircraft allocation tactical decision rules.
- Group size, by aircraft type, by mission.
- Sortie rates, by aircraft type, by mission.
- CAS missions flown per battalion request.

b. Inputs Generated by the Model

- Previous aircraft attrition.

- Battalion area requests for CAS.

c. Outputs

- Number of shallow CAS missions flown, by type, by day, by battalion area.
- Number of all other missions, by type, by day, by sector.
- The numbers of aircraft flying together, by type, by mission, by sector.

d. Assumptions

- One aircraft with a sortie rate of two is equivalent to two aircraft with sortie rates of one.
- The air war is conducted on a sector (corps) basis. Higher level cross assignment may be performed by the tactical decision rules on a daily basis.
- The fraction of interceptors engaging a given type of attacking aircraft is the same as the fraction of the total attacking force consisting of that type.
- Initial launches are simultaneous.
- Subsequent aircraft are launched at uniform intervals.
- Insofar as possible, requests for close CAS will be filled at the expense of deeper CAS.
- In the basic model, air POL consumption and air ordnance expenditure are bookkeeping entries. Any resulting operational constraints must be programmed by the user into the tactical rules.

6. Discussion

a. Basic Structure

Three of the models, CEM, IDAGAM and VECTOR, are basically accounting in nature. The allocation decision between the principal missions — air defense, airbase attack, close air support and interdiction are based on strategy input by the user. (In the case of VECTOR, the logic itself is input by decision rules, allowing the allocations to be based on any desired measures of the course of the battle.) LULEJIAN in contrast develops these

allocations within the model based on a game theoretic algorithm. All of the models incorporate one or more built-in procedures for developing allocations to associated missions such as escort and suppression, and for making suballocation decisions such as the decision to escort airbase attack aircraft of type A rather than to escort close air support aircraft of type B. Currently VECTOR contains the fewest logical suballocation routines; however, the tactical decision rule structure allows the number to be set by a user. In VECTOR the attackers suballocations are input by decision rule while the defenders suballocations are linearly determined within the model. CEM alone contains a procedure to allocate air away from CAS to CA if air attrition exceeds a threshold level. IDAGAM contains procedures to suballocate aircraft to the antiaircraft suppression mission based on the density of antiaircraft guns and SAMs. IDAGAM also contains procedures to suballocate CAS strikes to specific corps sectors and to suballocate airbase attackers to strike particular airbases. LULEJIAN alone examines some measure of the overall outcome of the war and using a structured search endeavors to find the best allocation strategy from the eighteen candidates for each side. The resulting strategies are adopted theater wide.

b. Geographic Representation of Air

The models differ in the numbers of discrete locations in which air interactions can occur. In CEM, the interaction are theater wide. CEM plays two airbases per side, one deep and one shallow. LULEJIAN is nearly as aggregated as CEM. Although the LULEJIAN theater can be divided into two air regions per side, each with its own inventory of aircraft, the percentage aircraft allocations to missions must be the same in both regions. Interdiction is played theaterwide. IDAGAM plays air at the region (field army) level. Each side may have individual inventories at about seven airbases. An input percent of the

aircraft in each region interact with the aircraft in each opposing region. IDAGAM gives the most extensive play to consideration of aircraft range. VECTOR treats air interactions at the sector (corps) level. Each corps is assumed to have one notional airbase. Air combat interactions in each corps area are independent of interactions in adjacent areas. Model logic to mass air support geographically is present in all four models. In VECTOR massing occurs within sectors, and in IDAGAM massing occurs within regions. CEM can mass theater CAS sorties across original region boundaries as a consequence of the sector adjustment procedures, and as a result, the apportionment of CAS in CEM is probably the most similar to the actual physical procedure. LULEJIAN linearly apportions regional CAS to sectors based on total sector ground maneuver force densities.

c. Force Resolution

IDAGAM and VECTOR offer the user more capability to depict differences in aircraft types than do CEM and LULEJIAN. IDAGAM currently treats ten aircraft types, ten air-to-ground munitions loads plus six range/payload degradation factors. These categories totals can be increased, at the expense of computation time without alteration of model logiç. VECTOR treats up to seven aircraft types, with a similar munition structure to IDAGAM. LULEJIAN treats five aircraft types. CEM treats two aircraft types. The general missions accomplished by aircraft are similar in the models — close air support, airbase attack, air defense or air intercept and interdiction along with suppression and escort. Each model allows some further breakdown of missions. VECTOR in particular allows the user to structure up to five specialized missions using the tactical decision rules procedure. IDAGAM gives relatively more extensive play to intercept and suppression missions than do the other models. VECTOR and LULEJIAN contain more diversified interdiction missions.

d. <u>Logistic Factors</u>

VECTOR keeps account of munitions and POL consumption for aircraft. LULEJIAN and IDAGAM keep account of a generalized air supply and, based on shortfall, linearly degrade air potential. CEM does not consider logistic limitations.

e. <u>Common Assumptions</u>

It is generally assumed that one aircraft with a sortie rate of two is, on a daily basis, equivalent to two aircraft each with a sortie rate of one. In the case of reactive interactions such as defending against an attacker, this assumption fails.

Weather, visibility and terrain are not significant to the allocation of aircraft.

Initial transients such as surprise attacks are not being modeled. Both sides begin simultaneously and proceed at a uniform rate.

E. AIR-TO-AIR INTERACTIONS

1. Topic

This section discusses the air-to-air combat between defensive aircraft and the opposing strike aircraft and escorts.

2. CEM

In CEM, the detection and intercept process is aggregated into one parameter, PDIP. The fraction of all attack and escort aircraft, exclusive of CAS aircraft, which is detected is $1-(1-PDIP)^{I/A}$ where I/A is the ratio of interceptors to all attackers (attack aircraft and escort aircraft on armed reconnaissance/interdiction and counter-air). The numbers of attack aircraft and escorts killed is the above fraction, multiplied by the numbers of penetrating attack aircraft or escort aircraft. The attack aircraft and escort aircraft which were unsuccessfully attacked by interceptors then engage the interceptors. The interceptor losses are calculated by multiplying the number of attackers by a kill probability. CAS aircraft do not engage in air-to-air combat.

In CEM, all penetrating tactical fighters (attack aircraft) which are engaged but not destroyed by defending fighters are assumed to jettison their loads and, after endeavoring to destroy their opponents, return to base, thereby aborting the principal mission. Engagement by ADA does not cause mission abortion.

a. Inputs by User

- The detection and intercept parameter PDIP.
- Four probabilities of kill: interceptors versus attack aircraft and escort aircraft, and attack aircraft and escort aircraft versus interceptors.

b. Inputs Generated by the Model

- The numbers of attack aircraft, escort aircraft, and interceptors which are flying their respective missions.

c. Outputs

- Numbers of attack aircraft, escort aircraft, and interceptors engaged.
- Numbers of attack aircraft, escort aircraft, and interceptors destroyed.

d. Assumptions

- Interceptors engage all penetrators, both attack and escort, simultaneously and in proportion to the relative numbers present.
- The probability of detection and engagement of a penetrator is independent of penetrator type (notional type aircraft employed).
- CAS aircraft are not subject to air interception.
- Interceptors are well coordinated.

3. IDAGAM

IDAGAM treats in detail two aspects of air-to-air combat. The first of these is the sequence of interactions; the second is the form of the attrition equation between individual combatants. (Sequence is hard wired into the model.)[1] The attrition equation form may be varied among five alternates,[2] which permit examination of one-on-one or many-on-one binomial form and the two Lanchester forms. Detection probability is assumed to be independent of target and shooter type but may depend on engagement type and location. It is input as the probability that the specific shooter will detect the specific

[1]For the sequence of interactions see IDA Report R-199 Ground Air Model, Volume III, page 41-3. Note m=1 and 2 are interchanged.

[2]For the equation options see Report R-199, Volume I, page 34-42.

target, region wide. Attrition is calculated in detail during ingress. Egress attrition is calculated as an input percentage of ingress attrition. All calculations are made daily. There is no logic for mission abortion.

a. Inputs by User

- Probability of detection, by type mission (attacker, escort, defender, suppressor), by location and by fly-by versus attack status.
- Probability of kill given detection, by target type, by shooter type, by attack, defend or escort status of shooter.
- Attrition equation selection, by engagement type (8 types).
- Attrition ratio, egress/ingress.

b. Inputs Generated by the Model

- Daily sorties, by aircraft type, by mission type, by area.

c. Outputs

- Aircraft kills, by mission, by type, by source of kill.

d. Assumptions

- The sequence of interactions described above is valid or, alternatively, attrition is sufficiently small as to make sequence unimportant.
- Interactions are region wide.
- The following assumptions are grouped by attrition equation:

  (1) Multiple engagement binomial:

  - Redundant kills can occur.
  - The likelihood of detection is dependent on the number of targets.

  (2) Single engagement binomial:

- As in the multiple engagement binomial with the added assumption that although shooters may detect several targets the shooter can engage only one.

(3) Exponential forms of the binomial:

- All of the assumptions in the binomial forms and, in addition, the assumption that attrition is relatively low.

(4) Lanchester linear form:

- Only live targets are engaged.
- The probability that an individual target is engaged is proportional to the number of shooters only.

(5) Lanchester square form:

- Only live targets are engaged.
- The probability that an individual target is engaged is proportional the ratio of shooters/ targets.

4. LULEJIAN

In LULEJIAN the user inputs a maximum capability of the defense to detect attacking aircraft. The fraction of attacking aircraft actually detected is the lesser of D/T or (1-exp (.20 D/T) wherein D/T is the ratio of an input maximum number of penetrators which can be detected to the actual number of penetrators present. This fraction determines the fraction of attacking aircraft which <u>can</u> become involved in air-to-air combat. The fraction of these which <u>do</u> become engaged is then calculated using a similar form, $(1-\exp(\frac{TPT}{D}))$. The term TPT/D is the ratio of the total potential for engagement of the escorts to the number of defenders available for engagement. Given engagement, both defender and escort simultaneously try to destroy one another. The fractions killed are determined by multiplying the number of aircraft engaged by an exponential of the form (1 - exp (-RPk)) where R is the ratio of the engagement potential of the shooter divided by the engagement potential of the target and Pk is the probability of kill given engagement.

After the escort-defender interaction, defenders endeavor to engage the attack aircraft. All defenders which were heretofore unengaged and an input fraction of the defenders which were engaged but were not destroyed are available. The fraction of defenders which engage is determined as before except the exponent now contains the ratio of the potential for engagement of the defenders divided by the number of attackers. The losses to attacker and defender are calculated as were the losses between escort and defender.

In LULEJIAN, the defense interceptors which have not been engaged by the escort aircraft and an input fraction of those that have survived combat with the escorts attempt to engage the attack aircraft. All attack aircraft which are engaged are either destroyed or abort the mission and return to base. Engagement by ADA or SAM does not cause mission abortion.

a. Inputs by User

- The maximum number of penetrators the system can detect.
- The engagement potential of each defender type against each escort and attacker type on each attack mission.
- The engagement potential of each attacker type on each mission type against each defender type.
- The engagement potential of each escort type against each defender type.
- The kill potential or probability of kill of each defender type against each attacker or escort type and vice versa.
- The percentage of defenders which, having survived the duel with escorts, can subsequently engage attackers.

b. Inputs Generated by the Model

- The number of attacker, escort and interceptor sorties by region, by aircraft type and by attacker target.

c. Assumptions

- The capability of the defense has an absolute saturation point.
- All shooters obtain information on the whereabouts of all detected targets but the shooters do not coordinate their attacks.
- An attacker can shoot at a defender only once.
- An input percentage of defenders surviving an engagement with escorts can subsequently engage attackers; otherwise, defenders can only engage once.
- Engaged attackers abort their primary missions.
- Escort-defender engagements occur simultaneously and precede defender-attacker engagements.
- The conditions for using the Poisson distribution of kills (simultaneous target selection and attack).

5. VECTOR

In the VECTOR model, aircraft penetrate in escorted groups, initial group size being an input. Interceptors make contact with the group with an input probabability PD. Each escort attacks an interceptor in contact with probability of success PC, input by shooter and target type. Simultaneously interceptors attack escorts with an input probability of success. No escort or interceptor is attacked more than once. Excess escorts are idle. Interceptors which do not attack escorts can attack the penetrating attack aircraft. Attack aircraft jettison their ordnance and engage the interceptors. Attacker and defender engage simultaneously in a one-on-one duel. Attack and escort aircraft are assigned to specific missions by input decision rules. In contrast interceptors are linearly apportioned against attackers. This structure permits offensive, but not defensive, gaming in the selection of assignments.

a. Inputs by User

- Attack group size, by type, by mission.
- Escorts by type, by attack group they are escorting.

- The probability that a group of attack aircraft is detected and engaged, by attacker type, by mission.
- The probability that an escort kills a defender in the duel, by escort and defender type.
- The probability that the defender kills the escort, by escort and defender type.
- Comparable probabilities of kill between defender and attacker types.

b. Inputs Generated by the Model

- Attack, escort, and defense sorties, by aircraft type, by mission, by sector.

c. Outputs

- Aircraft killed, by type, by mission, by sector, by shooter.
- Aircraft aborting, by type, by mission, by sector.

d. Assumptions

- All air combat is strictly one-on-one.
- Aircraft can engage only once per sortie.
- Air combat is restricted to forces in sectors.
- Coordination among all attackers and among all defenders is perfect.
- No defenders engage attackers unless all escorts have been engaged.
- Excess escorts or defenders are useless.
- All air combat occurs as a single set of events, with no distinctions regarding location.
- Acquisition percentage is constant in all sectors.

6. Discussion

One obvious way in which the models vary is in the variety of types of aircraft interacting. As was discussed in the section on organization of the theater air forces, IDAGAM permits the largest number of types of aircraft, followed by VECTOR

and LULEJIAN, with CEM in particular, allowing less variety. In IDAGAM and VECTOR, the numbers of aircraft types can be further increased by redimensioning and recompiling, albeit at the expense of computer storage and time. The ability to vary the numbers of types to suit a particular study application is desirable.

a. Sequence

There is variation of sequence among models. IDAGAM contains the most detailed, explicit sequence of attacker-defender-escort interactions. In IDAGAM also, the penetration aircraft encounter defenders in two locations (battlefield and at air bases) whereas other models play air-to-air encounters in one place. Each model has its own sequence of engagements or plays simultaneous engagement. Unless attrition is abnormally high, sequence is of little importance. No real case can be made for any model sequence over any other sequence.

b. Information Flow

An area of poorly documented difference between models is in the degree of assumed information flow and coordination among defenders or among attackers. These assumptions deal with the capability of the command and control systems for each side. In CEM, the C&C system postulates the following: A central system detects and directs the engagement of some fraction of penetrators $(1-(1-PDIP)^{I/A})$. Each attacker detected/engaged is then efficiently attacked by an interceptor and destroyed according to a stated probability of kill, (Pk_A). Attackers (A) killed by interceptors (I) equal $\left[A\ (1-(1-PDIP)^{I/A})\ Pk_A\right]$. Survivors of the attackers (SA) destroy interceptors at a given Pk_I. Interceptors killed equal $\left[(SA)\ (Pk_I)\right]$. All survivors of the engagement return to base including interceptors not engaged. Attackers not detected/engaged continue on their missions without further interference from interceptors. VECTOR also

assumes that a central system detects all penetrators and provides this information to each interceptor. VECTOR then assumes that the C&C system efficiently directs each interceptor to an individual penetrator escort until one interceptor is paired with each escort. Remaining interceptors then pair with attack aircraft. This pairing sequence is logical based on the missions of the defenders. IDAGAM assumes no centralized detection. The coordination of the engagement may be perfect if a Lanchester attrition option is selected. If a binomial form is selected no coordination of the attack is assumed. LULEJIAN assumes that the escorts, not the defenders, engage in an uncoordinated search for defenders. Each escort has a user input "potential" to locate a certain number of defenders, the number of defenders contacted being normally related to this capability. It is then assumed that the locations of all contacted defenders are provided to each escort and vice versa. Escorts and defenders then randomly pick an opponent and attack once.

c. Saturation

Saturation is also related to command and control. The treatment of saturation varies among models. Saturation effects can appear in two aspects of the air-to-air engagement. The acquisition system can be saturated, which limits the ability of the defense system to acquire additional targets. Secondly, the engagement capability of the defense system can be saturated. In CEM, acquisition is dependent only on the ratio of interceptors to attackers, which implies a physical situation in which the absolute numbers of attackers and defenders are irrelevant to the chance that an individual aircraft will be engaged. This means no geographic saturation occurs. The only saturation is a function of multiple, hence wasted, acquisitions. The engaged aircraft can be fired on, at most, once. LULEJIAN does allow an input upper limit on the number of penetrators which

can be acquired, thus providing an upper bound on acquisition capabilities. An exponential approximation to the single engagement binomial equation[1] is used to scale the number of penetrators available for acquisition below this input limit. Other than this, saturation is a binomial effect, as in CEM. In VECTOR, saturation during acquisition is not modeled; hence, it is assumed constant. Once acquisition has occurred interceptors and penetrators are assumed to pair off in an efficient, coordinated manner for pure one-on-one duels; hence, even the binomial or random target selection saturation effect is not modeled. IDAGAM allows varied assumptions on the degree of random versus efficient target selection. The form commonly used, the single engagement binomial, assumes that target selection is random; hence, a saturation phenomenon occurs due to wasted, redundant acquisition. This form differs from the CEM and VECTOR forms in that, although a shooter may only shoot once, a target may be shot at several times. IDAGAM does not play geographic saturation.

d. Abortion

All models except IDAGAM consider that engaged attack aircraft abort. IDAGAM needs this addition.

e. Group Size

The concept of a group engagement in VECTOR is a realistic alternative to the individual actions postulated in the other three models. It avoids the difficulty in defining individual detection probabilities as in IDAGAM and reflects perhaps a reasonable level of command and control.

[1]It may be possible to state assumptions which lead directly to the Poisson distribution. Such assumptions have not been explored.

f. General

LULEJIAN probably considers all factors of air-to-air combat in the most reasonable overall way. The idea of geographic saturation and escort-initiated combat are good for LULEJIAN. However, since it is most difficult to associate model parameters with collectable data, analysis using LULEJIAN will be difficult.

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F. COMBAT AIR SUPPORT

1. Topic

This section discusses modeling of combat air support (CAS) provided to ground forces in contact.

2. CEM

The CAS sorties available to the command echelons (Theater, Army, Corps, Division) are allocated to subordinate echelons in response to estimated need. The logic for this is the same as the logic for the allocation of artillery. Each CAS sortie has three input firepower values, one each against tanks, light armored vehicles, and personnel. The effective firepower value contributed in each subsector is the product of the number of sorties times these firepower values degraded by a terrain factor. This value of CAS and the value of ground weapons are then summed to determine three total firepower values as applied to the three target types. Target casualties in each of the three categories are determined by an exponential equation of the form T(1 - exp(- K(ATFP)/T)) wherein K is an input calibration coefficient and, in this example, ATFP is the total anti-tank firepower. T is the population present.

FEBA movement is a user-input function of firepower ratio, terrain and posture. CAS contributes to the firepower values. Firepower values are modified to account for the number of each type target which is present. The contribution of CAS firepower is treated in a manner equivalent to the contributions of other shooters.

a. Inputs by User

- Firepower value per CAS sortie against tanks, light armored vehicles and personnel.
- A calibration coefficient, K.
- Fractions of weapons totally killed and killed repairable.

- FEBA movement as a function of firepower ratio, terrain and posture.

b. <u>Inputs Generated by the Model</u>

- Number of sorties assigned to each subsector each period.
- Firepower contributions of other shooters in the subsector against each target type.
- Target inventories.
- Firepower ratio.

c. <u>Outputs</u>

- Numbers of tanks, light armored vehicles and personnel lost.
- FEBA movement.

d. <u>Assumptions</u>

- CAS sorties are uncoordinated with one another or with ground shooters.
- Redundant kills occur.
- The percentage of targets present which are acquired and killed by air is dependent only on the total number of shooters of all types and the total number of targets in a class, such as tanks.
- The type of target kill, repairable or unrepairable, is independent of the mix of shooters.

3. <u>IDAGAM</u>

On combat air support and interdiction missions, each aircraft type has an input nominal munitions load. Each of these munitions has an input potential kill probability against each type of ground weapon. An allocation of munitions against each ground weapon type in a standard target force is also input. This allocation is linearly varied in the model to account for variation in the relative sector population of each target type. The number of sorties supporting each sector

is multiplied by the munitions load per sortie times the allocation per munition to obtain an air potential target kill capability. This, in conjunction with a ground potential, determines a total potential kill, and a value to this kill. The meaning of value depends on the force ratio methodology. Using a user-selected method, a force ratio is computed and a scale of attrition is determined by table look up. This scaling of attrition is then applied to all elements in the potential kill list yielding a list of actual kills by both air and ground weapons. The proportions of weapons types on the potential kill list and those actually killed is unchanged. Only the overall level of kills are scaled.

CAS contributes to FEBA movement, which is an input function of force ratio. The attrition capability of air, multiplied by a weighting factor, is added to the attrition capability of ground when the force ratio is calculated. The weighting factor, which increases the ability of air to influence FEBA movement within the sector, reflects the ability of air to mass within the sector and cause adjacent sectors to withdraw so as to avoid encirclement. Air is assumed to mass in a portion of the sector.

All CAS sorties available in a region are assigned to one or more sectors so as to achieve an input force ratio, remove a front to flank constraint or minimize the maximum penetration.

a. Inputs by User

- Munition load by aircraft type.
- Standard allocation of each munition type against each ground target type.
- Potential kills per munution against standard force by munition type.
- Percentage force attrition by force ratio by posture.
- FEBA movement by force ratio.

b. Input Generated by the Model

- Adjusted allocation due to nonstandard mix.
- Sector to receive CAS.
- Subsector factor for air concentration.
- Force ratio.

c. Outputs

- Target kills, by shooter, by target, by sector.
- FEBA movement.

d. Assumptions

- Munitions performance is independent of delivery aircraft type or terrain.
- Target acquisition can be treated as one sector-wide probability which can be scaled among shooters and targets in accordance with the input kill probability.
- The potential engagement is perfectly coordinated. One scaling models all lack of coordination and all acquisition.

4. LULEJIAN

In LULEJIAN, combat air support sorties may have both target acquisition and target attack capabilities and may be directed against forces in contact or against forces providing supporting fire.

In order to destroy armored and light armored targets, the target must be in contact and located, with location a subset of contact. The "armor locational potential" of the sortie, an input, is added to an equivalent locational potential for other support elements, and an expression of the following form is computed.

$T_1 = T_c\ (1 - \exp\ (-RF))$, wherein T_c is the total armor contacted. R is a constant to apportion fire between tanks and light armor and F is the locating potential. The outcome,

T_1, is the number of tanks which may suffer attrition. A similar expression is computed for light armor. CAS sorties do not locate contacted infantry but instead directly attrite the contacted force. The expression used to calculate infantry losses to support fires is an exponential form, as above, with the exponent, $(-Fd/x)$ wherein F is a casualty potential in terms of area, d is a target density in terms of personnel per area and x is the number of contacted infantry.

Attrition to armor and light armor is calculated using the same form as for locating armor and light armor, above, except that targets located are substituted for targets contacted and F is a kill potential rather than a locating potential.

At the user's option, sorties may be directed against artillery and armor in support. Sorties can both suppress and kill these elements. No exchange of information pertaining to these targets is assumed between ground and air; hence, the aircraft must find their own targets. Once found, targets can be attacked. Acquisition is modeled as an uncoordinated area search process. Attrition is modeled as a point attack process with target information exchange among shooters. Users input acquisition and attrition potentials per sortie.

The effects of CAS sorties are treated identically to the effects of ground actions in trading area for survivability to determine overall attrition and FEBA movement.

a. Inputs by User

- Locating and attriting potential of each sortie against armor and light armor in contact; attriting potential against infantry in contact; locating and suppressing potential against armor and artillery in support; fraction of suppressed targets destroyed, by target class, by aircraft type.
- Allocation of CAS sorties against forces in contact and in support.

b. Inputs Generated by the Model

- Numbers of contacted and located targets.
- Numbers of sorties against contacted and support forces in each sector.
- Locating and attriting potentials of other contributory systems.

c. Outputs

- Numbers of armored, light armored, infantry and artillery killed or suppressed.

d. Assumptions

- Information exchange between all shooters about targets in contact is perfect.
- Information exchange is perfect between shooters of each type against targets in support.
- All shooters are uncoordinated in target selection.
- Acquisition and kill capabilities against any one target type are independent of the situation for other target types.
- Aircraft loads for a given type aircraft on a given mission are fixed.

5. VECTOR

Each day a certain number of sorties are available for CAS to each sector. All sorties are assigned against deep CAS targets (sector reserves and artillery) unless a call for shallow CAS support is received from a battalion area. Such calls may be preplanned or may be generated in accordance with the course of the battle. Sorties are assigned to shallow CAS in battalion areas in response to these calls in preference to deep CAS. More sorties can be called to shallow CAS than are physically available and, in such cases, the sortie is provided but an accounting deficit message is reported. The excess sorties are subtracted from the number available the following day.

Calls and preplanned support are determined by a user-input tactical decision rule.

Target damage from shallow CAS strikes is calculated in two ways. The total damage caused by point attack weapons is the product of some input expected lethality times the number of strikes. Percentage damage caused by area fire weapons is $1-(1-C)^S$, where S is the number of sorties and C is the area ratio of munition coverage area to total area. C is an input which is invariant across sectors but varies by attacker and target type and by the type of combat (infantry or armor heavy, red or blue).

Deep CAS effects are calculated in the same manner as shallow CAS point attack damage, above. The target damage caused is independent of the target force composition.

a. Inputs by User

- Tactical decision rules to control requests for shallow CAS. These must be programmed in FORTRAN by the user.
- Preplanned calls for shallow CAS through user programmed tactical decision rules.
- Targets killed per shallow CAS sortie by point attack munitions, by target type, by aircraft type, by combat type.
- Percentage of targets killed by area attack munitions per sortie, by target type, by aircraft type, by combat type.
- Targets killed per deep CAS sortie by target type, by aircraft type, by combat type.

b. Inputs Generated by the Model

- Targets by type in the battalion areas.
- Calls for shallow CAS, by time interval by battalion area.
- Sorties available for shallow and deep CAS, by sector.

c. Outputs

- Number of shallow CAS sorties.
- Number of deep CAS sorties.
- Targets killed by type, by location.

d. Assumptions

- CAS capability is limited to sector assets.
- The CAS munition load of each aircraft type is fixed.

6. Discussion

Two of the four models, VECTOR and LULEJIAN, treat separately CAS sorties against maneuver units in contact and CAS sorties against support forces such as artillery. IDAGAM also allows attacks of on-line maneuver forces and support forces but does it by input fractional allocation of each sortie, not by treating them as separate missions. VECTOR allows attack of close-in reserves. IDAGAM allows attack of region (army) reserves. LULEJIAN does not allow attack of reserves. CEM does not allow attack of reserves or support forces. Since the Air Force expresses great interest in the mission of attacking reserves near the front line, this mission should be addressed in the model in a way which differentiates it from the mission of attacking forces in contact. The VECTOR treatment of this aspect appears best.

a. Requirements for CAS

The models differ in the method of determining the local requirement for CAS. VECTOR assumes that each corps has a fixed allocation of sorties which are internally divided between deep and shallow strikes based on the number of preplanned and combat-generated requests for shallow CAS. IDAGAM apportions sorties on an army (region) basis to particular corps in order to minimize penetration and flank

constraints, or to achieve force balance. CEM contains a complex, multi-level logic for the allocation of reserves, fire support and air to subordinate levels. CEM does not develop requests for support; rather, support is apportioned from above based on perceived requirement. The LULEJIAN allocation system is the most simple. Sorties are simply allocated to sectors in proportion to the total, Red and Blue, maneuver units in the sector. The VECTOR allocation can be substantially altered by rewriting a tactical decision rule. IDAGAM can be somewhat altered based on the option selected. For analysis it is probably most useful if the allocation is either based on a very simple rule, such as LULEJIAN, or on a changeable basis such as VECTOR. In any event it is important that the output show where the model logic is allocating the CAS. IDAGAM needs this improvement.

b. Command and Control

In CAS as in air-to-air combat, different assumptions are made as to command and control or coordination. One model, LULEJIAN, assumes that some target information is shared by ground and air forces, and among individual aircraft. LULEJIAN then assumes that aircraft select from among these targets in an uncoordinated way. CEM assumes all shooters, air and ground, are uncoordinated. IDAGAM in contrast assumes perfect (Lanchester Square) coordination of all air and ground fire and, as currently used, perfect air acquisition of ground targets. Then IDAGAM inserts a massive, generally applied "discoordination factor", currently of the order of 1/20, to correct for the assumed perfection. This factor is input as the casualty function. VECTOR assumed that a constant, unchanging amount of target information is provided to each point-attack CAS aircraft. It, for instance, assumes that the FAC has told the pilot that a tank is there. The probability of hitting the tank is hence assumed fixed. This VECTOR

assumption may be good for close air support. It is tenuous for pilot-acquired targets attacked during deep CAS. In all models, the treatment of command and control, which also implies the treatment of ground target acquisition, is a weak area.

c. Munitions

IDAGAM contains a useful feature absent in the other models. Rather than using a single input parameter to represent a capability for an aircraft against a ground target, IDAGAM uses two input parameters: the capability of an air munition against a ground target; and the capability of an aircraft to carry the munition. Although equivalent mathematically, this method is more logically appealing than the alternative. If a weapon varies in capability depending on aircraft delivery accuracy, two weapons can be input in lieu of one.

d. Firepower Equivalence

Three models always treat air delivered firepower as equivalent to ground delivered firepower in determining FEBA movement, and the fourth, IDAGAM, can do so if desired by the user. IDAGAM alone contains a rather artificial scheme which may be used to make air-delivered firepower more influential than ground-delivered firepower in moving the FEBA. In the author's judgement, the rationale for this preference is tenuous.

e. Effects

Three models make the assumption that the contribution of CAS is purely attrition. LULEJIAN assumes target information is also generated.

f. Disruption

Each model tacitly assumes that the delay and disruption caused by air is in the same proportion to the lethality

caused by air that the delay and disruption caused by ground is to the lethality caused by ground systems.

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G. AIR INTERDICTION

1. Topic

In this section air interdiction of ground targets well behind the FEBA, for example, in the army rather than corps area, is treated. Close interdiction is treated as part of close air support.

2. CEM

In CEM, interdiction is treated as a "yes/no" phenomenon. If the number of successful, that is surviving, interdiction sorties flown by one side exceeds a user-input threshold level, the opponent is assumed to experience an unfriendly air environment and all replacement and supply flows experience an additional delay. If the threshold is not exceeded, no additional delay is imposed.

a. Inputs by User

- Threshold levels.
- Delays.

b. Inputs Generated by the Model

- Successful interdiction sorties.

c. Outputs

- Delay, if any, in resupply and replacement operations.

d. Assumptions

- That the value of interdiction lies in the delay it generates rather than the casualties it produces.

3. IDAGAM

IDAGAM treats interdiction as two phenomena, namely the air attack of personnel and weapons in the regions, and the air

attack of supplies in regions. The COMMZ is not attacked. The number of personnel and weapons in the region which are destroyed by interdiction is the product of the number of aircraft sorties multiplied by the number of munitions per aircraft per sortie multiplied by some kill capability per munition multiplied by a linear factor. The linear factor adjusts the relative kill rates based on the actual proportions of the targets in the region if these proportions differ from the equivalent proportions in a standard force. Interdiction of supplies occurs as a result of a user-input factor which diverts a percentage of sorties from attack of divisions in reserve (IDR) to attack of supplies. Damage to supplies is calculated by multiplying the number of successful sorties by the munition load per aircraft by the quantity of supplies destroyed per munition. The attack of supplies in sectors is not treated here. It is caused by CAS and the ground-to-ground interdiction.

a. Inputs by User

- Munitions load per aircraft.
- Munition capability to destroy each target type, per munition.
- Munition capability to destroy supplies, tons destroyed per munition.
- Percent of IDR sorites diverted to supply interdiction.
- The composition of a standard force.

b. Inputs Generated by the Model

- IDR sorties flown.
- Reduction in sorties due to aircraft loss or diversion.
- Actual forces in regions.

c. Outputs

- Personnel casualties and weapons destroyed by type, by region.

- Supplies destroyed per region.

d. Assumptions

- The probability of an aircraft acquiring any generalized target is dependent on aircraft and munition type only.
- The probability of an aircraft acquiring a particular target type is dependent only on the relative proportions of that particular target to all targets on the battlefield.
- Redundant kills do not occur.
- Interdiction occurs at the region (field army) level only.
- The capability of the logistic network is not degraded by air interdiction.

4. LULEJIAN

The LULEJIAN model represents five forms of interdictive attack: attack of supply depots; attack of airfield depots; attack of SAM depots; attack of logistics vehicles; and attack of the network capacity. Missions are allocated against each element in linear proportion to the productivity of a mission of each type. In four of the five cases, the probability of acquiring N_{acq} targets to attack is a function of a per sortie coverage factor, P, the number of sorties, a, and the number of targets present, N. The form of the acquisition equation is $N_{acq} = N\ (1 - \exp\ (-Pa))$. Only the excess of the network capacity over a specified (input) proportion of the initial capacity is assumed to be at risk. Attrition to acquired elements is calculated using a similar exponential form, with P redefined as a kill potential and N replaced by N_{acq}.

a. Inputs by User

- Acquisition factor per sortie, by aircraft and mission type.
- Kill capability per sortie, by aircraft and mission type.

- Percentage of initial network capacity which exists as bridges and is therefore at risk.
- Initial logistic network capabilities, tonnages and bridges.

b. Inputs Generated by the Model

- Sorties flown, by mission, by aircraft type.
- Current logistic network capabilities, tonnages and bridges.

c. Outputs

- Reduction in logistics network capabilities, tonnages and bridges.

d. Assumptions

- That the network is constructed in parallel (as opposed to series), and no choke points exist.
- That the number of detections and engagements is directly dependent on the number of shooters and the number of targets (except for bridges).
- That all shooters select among all acquired targets simultaneously and independently, thus leading to uncoordinated attacks which in turn cause overkill when the number of shooters approaches or exceeds the number of targets.

5. VECTOR

The VECTOR model does not distinguish interdiction per se. Instead, in addition to shallow and deep combat air support missions, VECTOR allows the user to specify individually five air attack mission types, each of which can destroy input quantities of forty-five target categories. Examples of these categories are ground POL in reserve or aircraft ordnance at airbases. The total quantities destroyed are these input factors multiplied by the number of successful sorties. Strikes are carried out on a sector basis.

a. Inputs by User

- Quantity of target category destroyed, per aircraft type, per mission type, per target category type.
- Aircraft allocation rules.

b. Inputs Generated by the Model

- Target populations.
- Sorties flown per sector, by aircraft and mission type.

c. Output

- Target kills, by target type, by sector.

d. Assumptions

- The number of targets acquired and killed is independent of the target population as long as the population is non-zero.
- There are no redundant kills.

6. Discussion

In the same way that acquisition appears to be the most difficult physical process to model, interdiction appears to be the most difficult mission to model.

a. Effects of Interdiction

Broadly speaking interdiction can have two effects on an opponent — attrition and disruption. Attrition occurs when off-line combat forces such as divisions in reserve are attacked and suffer casualties. Disruption is generated when the supplies necessary for the conduct of the war are destroyed or when the means to distribute these logistics are destroyed. All models treat one of these two aspects; LULEJIAN treats both.

Another form of disruption can occur, namely when the capability of a side to exercise command and control over combat

forces in terms of communication, movement and intelligence operations is diminished. None of the models treats the use of air resources to achieve this form of interdictive disruption. It is not clear that by limiting the treatment of interdiction to basically logistic denial that the most important of the foregoing effects has been treated.

A second general problem with logistic denial type models is that the payoff in actual operations is probably not linear. It seems to be generally agreed based on experience in WW II and RVN, that a, say, twenty percent reduction in logistic capability due to interdiction does not cause a comparable reduction in combat capability. This phenomenon is particularly true when reduction is imposed over long rather than short periods of time. In contrast, disruption can be effective if one element of supply, say, POL is essentially totally denied and this denial is effected in a short period of time. The upshot of this nonlinearity is that the coupling of the effects of logistic destruction in terms of tons lost, bridges destroyed or delays imposed with their actual effect on the combat capability of the forces is unknown. This problem area appears to be caused by the lack of a theory, not of modeling. Each model makes its own simplified assumption as to this linkage.

CEM contains a simple logic. If the number of sorties exceeds a threshold, the opponent experiences a fixed delay in replacement and supply flow. If the threshold is not exceeded, no delay occurs. Although it has intuitive appeal, this approach is so simplified that it appears to be of little use for analysis.

LULEJIAN uses exponential equations, similar to those throughout the model, to calculate the capability of interdiction aircraft to destroy supplies, and consequently, the amount of supplies destroyed. Also, the amount of supplies which can be moved through a transportation system of a given capacity

is computed using exponential relationships. Once the amount of supplies surviving interdiction is determined, the degradation of individual unit effectiveness caused by inadequate supplies is proportional to the fraction of required supplies which is unavailable.

The IDAGAM assumption regarding the effects of supply shortages is the same as that in LULEJIAN except that supplies are assumed to flow efficiently; hence, degradation due to interdiction is purely proportional to shortfall.

VECTOR contains no internal logic to degrade effectiveness due to supply deficiency. The capability does exist to input some degradation based on tactical decision rules. Substantial alterations to the attrition equations as a result of supply shortfall would be difficult to accomplish.

b. Interdiction of Reserves

As was mentioned, IDAGAM permits the attack of reserves which are located to rear of the sectors. The attrition caused by these sorties against reserves is calculated in a manner similar to the calculation of attrition to ground forces by CAS sorties except for the absence of the "discoordination function." This function, called in the model the casualty function, reduces the effectiveness of CAS by an order of magnitude to account for imperfect acquisition, discoordination of attack and so forth. The user must exercise caution to assure that the effectiveness values input to the model for interdiction reflect this difference in methodology. If this is not done, interdiction will be overstated vis-a-vis the effectiveness of CAS. None of the other models classifies any attack of reserves as interdiction.

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H. AIR BASE ATTACK

1. Topic

This section discusses the air attack of opposing air bases and aircraft on the ground.

2. CEM

Input fractions of the two aircraft types on the forward airbase are at risk. These aircraft are sheltered up to an input number of shelters and the remainder are considered to be in the open. Successfully penetrating attackers are divided in proportion to these numbers of sheltered and unsheltered targets. Given N attackers and T targets, each target is attacked by N/T attackers; hence perfect divisibility of the attackers is assumed. Kills are calculated using a binomial attrition equation.[1] Only the contents of a shelter may be destroyed, not the shelter itself.

a. Inputs by User

- Shelter inventory
- Probabilities of kill of sheltered and unsheltered aircraft. The probabilities of detection are incorporated in the kill probabilities.

b. Inputs Generated by the Model

- Current aircraft inventory by type.

c. Outputs

- Number of aircraft destroyed on the ground, by type, by sheltering status.

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[1]The term (-PAP) in the equation in Part I, page 85, of the CEM IV manual should read (1-PAP).

d. Assumptions

- Detection of targets is perfect.
- The coordination, or point fire distribution of the attackers, is perfect. This assumption allows an attacker to kill more targets than the numerical value of Pk, i.e., one attacker with a Pk of .5 engaging ten targets kills .67 targets.
- All shelters which are attacked are assumed to contain aircraft.
- Shelters are not destroyed.

3. IDAGAM

IDAGAM contains built-in logic to decide which specific target at which specific opposing air base will be attacked by aircraft stationed on a particular friendly base. The logic computes a weighted sum of the sheltered and unsheltered aircraft at each base within range and apportions sorties in proportion to these weights. In the event no bases are within range of a particular attacker type, the model will reassign the attack mission to aircraft of the same type which are at a base within range. A threshold target density below which strikes will not be launched is input. When ABA missions are infeasible, aircraft which would otherwise be assigned to them are assigned to CAS.

Attrition to aircraft parked in the open, to aircraft parked in shelters and to the shelters themselves is calculated using a single engagement binomial form of attrition equation.[1] This attrition equation specifies a user input detection probability which is physically interpreted as the probability that an individual shooter detects an individual target. The value is independent of target type. Insofar as shelters are available

[1]The model contains five other optional formulations, three being exponential and two Lanchester. The assumptions inbedded in these alternate formulations differ somewhat from those here. See section on IDAGAM air-to-air combat.

aircraft on the ground are assumed to be sheltered. Aircraft are prioritized by type, and all aircraft of the higher priority are sheltered first. User input shelter locations are fixed while the number of usable shelters is determined by FEBA location.

A fixed quantity of aircraft, by type, by base may be held on the ground in a withhold status. Attrition to these aircraft is allowed.

a. Inputs by User

- Probability of detection, by aircraft type, by location, sheltered and unsheltered.
- Probability of kill given detection, by shooter and target type, sheltered and unsheltered.
- Minimum target density for attack.
- Aircraft shelter, by location.
- Sheltering priority, by aircraft type.
- Percent of time an aircraft is on the ground, by aircraft type.
- Quantity of aircraft to be withheld, by type, by base.

b. Inputs Generated by the Model

- Airbase attack sorties, by aircraft type, by target airbase.
- Sheltered and unsheltered aircraft, by aircraft type, by base.

c. Outputs

- Aircraft killed on the ground, by type.
- Shelters destroyed.

d. Assumptions

- That the attack of aircraft on the ground is a single engagement point fire phenomenon.

- That detection is dependent on the overall number of attackers and targets but is independent of target type.
- That aircraft immediately fill any empty shelters.
- That redundant kills occur.

4. LULEJIAN

Both tactical and airlift aircraft can be destroyed on the ground in the LULEJIAN model. Airlift aircraft are assumed to be in regions in proportion to the regional demand for supply tonnage. An input fraction of aircraft stationed on an airbase is assumed to be at risk. Tactical aircraft fill available shelters in proportion to the number at risk of each aircraft type. Airlift aircraft are unsheltered.

Attacking aircraft by type have a kill capability against aircraft in the open or aircraft in shelters. Aircraft in the open are attacked as point targets, with each attacker having an input Pk against each target type. Sheltered aircraft are attacked as area targets with each attacker having a lethal area for his munition load. The size of the area containing the shelters is input. Attrition to unsheltered aircraft is computed using an exponential equation of the form T killed = $T\ (1-e^{-ks/T})$, where T is defined as the number of targets, k is the per sortie potential and s is the number of penetrating sorties. For sheltered aircraft the equation is T killed = $T\ (1-e^{-ks/t})$ where t is defined as an area, k is defined in terms of an area potential per sortie, and T and s are, respectively, the number of targets and the number of penetrating sorties. Detection is perfect.

Shelters which are struck, whether occupied or empty, are destroyed and cannot be replaced.

a. Inputs by User

- Kill potential against unsheltered aircraft, by attacker aircraft type.
- Lethal area against sheltered aircraft, by attacker aircraft type.
- Number of shelters at start.
- Size of area in which shelters are located.
- Sortie times and availability used to determine at risk fractions, by aircraft type.

b. Inputs Generated by the Model

- Aircraft inventory by type, by region, to include airlift aircraft.
- Current shelter inventory.

c. Assumptions

- Target detection is perfect.
- The attack of targets is uncoordinated; redundant kills occur.
- An attacker is predestined to attack only sheltered or unsheltered aircraft, not both.
- When a sheltered aircraft is destroyed, its shelter is also destroyed.
- The probability of destroying an aircraft on the ground is independent of the aircraft type.

5. VECTOR

The treatment of airbase attack in VECTOR is similar to the treatment of interdiction and is one of the five user-specified missions. Among the forty-five possible target elements, unsheltered aircraft and shelters each appear twice, once in an area attack formulation using $N_k = N\ (1-P_k)^S$ and once as a point target using $N_k = SP_k$.

For each aircraft type there is an associated shelter type, thereby permitting selective sheltering. Attackers do not

discriminate among shelter types or types of aircraft during the attack. All types are attacked in proportion to the number present and all shelters and aircraft are equally vulnerable to attack by a particular attacker type.

An input percentage of shelters which have had their contents destroyed are destroyed themselves. New shelters can become available during the war.

a. Inputs by User

- Shelters, by aircraft type, by sector.
- Unsheltered aircraft destroyed per sortie, by aircraft type.
- Sheltered aircraft destroyed per sortie, by aircraft type.
- Fraction of unsheltered aircraft in an area destroyed per sortie, by aircraft type.
- Fraction of time an aircraft is not on the ground.

b. Inputs Generated by the Model

- Number of aircraft sheltered and/or unsheltered on the ground, by type, by sector.
- Number of successful attack sorties, by attacker type, by mission, by sector.

c. Outputs

- Aircraft killed on the ground, by type.
- Shelters destroyed.

d. Assumptions

- Area fire weapons attack first.
- The number of aircraft killed by area fire weapons is independent of hardstand dimensions.
- Point fire weapons kill no dead targets.
- Each attacker has a given probability of detecting a target, and that probability is independent of the number of targets present.

- Point and area fire attacks are independent of one another.

6. Discussion

In all models the benefits of airbase attack are expressed in terms of aircraft and shelters destroyed. (The airbases stay always intact.) No model allows airbases to be suppressed for a period of time.

a. Sheltering

All models treat sheltering but the degree of sophistication varies. At one extreme, CEM plays shelters which are undestroyable and are apportioned equally among the notional aircraft on a base. Attackers also apportion fire linearly against sheltered and unsheltered aircraft. IDAGAM, in contrast, plays shelters well. Shelters can be destroyed. Aircraft can be prioritized so that valuable aircraft are entirely sheltered in preference to less valuable aircraft. Shelter availability is contingent upon FEBA location. Both point and area fire attack modes may be modeled for the attack of sheltered and unsheltered aircraft. As in all IDAGAM air model engagements, options are available to model differing degrees of shooter coordination. VECTOR achieves a similar degree of detail by a somewhat different route. In VECTOR, there is a shelter level for each aircraft type, thereby allowing priority sheltering. Both point and area attack are permitted. The capability of acquiring targets is assumed in VECTOR to be independent of the number of targets available, a tenuous assumption. LULEJIAN does not permit priority sheltering. Shelters are apportioned linearly to all types of aircraft on the ground, based on the numbers of each type of aircraft. Attacking aircraft engage shelters using area fire, with the shelter area an input.

b. Allocation of Fire

IDAGAM contains internal decision logic which directs the attacker in the allocation of strikes against sheltered versus unsheltered aircraft. The objective is to maximize the number of aircraft destroyed on the ground. An improvement might be to input a quality factor for opposing aircraft and then allocate so as to maximize the quality destroyed. In other models, aircraft are allocated to attack sheltered and unsheltered aircraft according to input proportions. The input is independent of the status of the opponent.

c. QRA

IDAGAM has been modified to allow for a vulnerable, non-flying QRA aircraft level. The other models, except CEM, should be able to play QRA, but this capability is not documented.

d. Airlift Aircraft

LULEJIAN alone allows the attack of non-tactical aircraft on the ground

e. General

All in all, the treatment of airbase attack in IDAGAM is probably the most reasonable.

I. AIR DEFENSE ARTILLERY

1. Topic

This section examines the modeling of Air Defense Artillery (ADA) engagement of opposing penetrating aircraft. Both short range weapons, generally anti-aircraft gun (AAG), and long range surface-to-air missile systems (SAM) are treated.

2. CEM

Non-CAS ground-to-air attrition in CEM is the linear product of the number of penetrator sorties (2 types) multiplied by the number of notional anti-aircraft sites (1 type) multiplied by a probability that each site detects and kills a penetrator (2 penetrator types).

Attrition of CAS aircraft by ground fire is calculated similarly except the linear factor (ADA units per enemy unit x number of enemy units x aircraft lost per squadron per enemy ADA unit x number of friendly squadrons in support) is divided by the width of the supported friendly unit (Blue Brigade, Red Division). The width is measured in numbers of minisectors.

a. Inputs by User

- ADA units in division.
- ADA units in rear areas.
- Kills per ADA unit by penetrator type or squadron.
- Sector width.

b. Inputs Generated by the Model

- Squadrons in support of each sector.
- Penetration sortie.
- Divisions in sectors.

c. Outputs

- Penetrators destroyed, by type.

d. Assumptions

- No saturation effects occur.
- Regional air defense is independent of sector geometry.
- No redundant kills occur.
- There is no limit on the firing capability of ADA.

3. IDAGAM

IDAGAM is capable of playing two ADA systems. One system can be long range in that it can engage aircraft which are flying over its general location in route to target areas further to the rear. For this system, an account of inventory and expenditure of missiles is maintained. The second system is short range and can only engage aircraft on attack, escort or suppression missions in its general area. Systems can be located in sectors, regions or at any airbase. The same attrition equation options are available as are available in airbase attack or air-to-air combat. As in air-to-air combat, detection probability is independent of target aircraft type but is dependent on mission and location. Kill probability is dependent on target type and target mission but not on the location of the interaction.

a. Inputs by User

- Probability of target detection, by shooter type, by shooter location, by target status (fly-by or attack).
- Probability of kill by shooter type, by target type, by mission.
- Attrition equation choice, by interaction type.
- Initial SAM inventory.

b. Inputs Generated by the Model

- Number of aircraft available to be engaged by SAM and AAG at each location.
- Current SAM inventory.

c. Output

- Aircraft losses to SAM and AAG by location, by type.
- SAM inventory status.

d. Assumptions

- Only the long range systems can engage targets flying by.
- All SAM or AAG in the sector, region or at the attached airbase can engage all aircraft which attack the particular sector, region or airbase.
- Depending on the attrition equation chosen the shooters are coordinated or uncoordinated on target selection and may engage one or several targets.

4. LULEJIAN

Penetrating aircraft can encounter both area and point-deployed SAM and AAG. The area-deployed systems engage all penetrators other than CAS sorties as they fly by. Area SAMs engage prior to area AAGs. Both SAMs and AAG are assumed to be randomly deployed in the sectors. Their theoretical coverage is calculated by multiplying coverage width per site times number of sites and dividing by sector width. This number is then multiplied by the average number of SAMs fired and the P_k of the SAM to obtain TSKP, the total SAM kill potential against penetrators. The actual penetrator losses are equal to T (1-exp (-TSKP/T)) where T is the number of penetrators. Doubling the assumed number of corridors doubles TSKP. Attrition due to area-deployed AAG is calculated using a similar formulation.

At the penetrator objective, SAM and AAG coverage is assumed to be perfect; that is, all SAM and AAG are capable of engaging all aircraft suppressing or attacking in the area. The TSKPs or kill potentials of each system are calculated by multiplying the number of launchers by the average number of missiles fired by a tracking and a hit probability. The potential may be degraded by suppression and by supply shortages. Penetrator kills are calculated for kills by SAM then AAG using the same exponential form as above.

CAS attackers in sectors encounter SAM and AAG coverage calculated analogously to the single corridor coverage of fly-by penetrators by area-deployed SAM and AAG, except that the width used in calculating TSKP is the sector rather than the region width.

a. Inputs by User

- Number of ADA battalions, each with a fixed number of SAM and AAG sites area-deployed in each sector and each region, and point-deployed at each target area.
- SAM search width.
- SAM tracking probability.
- SAMs fired per site.
- AAG search width.
- AAG kill probability.
- Region width.
- Sector width.
- Number of penetrator corridors.

b. Inputs Generated by the Model

- Number of SAM and AAG sites neither suppressed nor destroyed.
- Site degradation due to supply shortage.
- Number of penetrator aircraft encountered by each site.

c. Outputs

- Number of penetrators destroyed by type, by location.

d. Assumptions

- SAM and AAG deployment is random; however, target engagement is perfectly coordinated.
- Target detection is perfect for point defenses. Detection by regional area defenses is based on their coverage area and the total area of the region.
- That a doubling of the number of axes of penetration doubles the number of air defenses encountered.

5. VECTOR

The penetrating group and its escorts are subject to attrition during ingress by three classes of air defense fire; short range fires near the FEBA, short range fires in the rear, and long range fires randomly located throughout the sector. A probability of kill of each target aircraft type by mission type is associated with each site type. All sites are assumed to engage in an uncoordinated attack on the penetrators. Saturation is not modeled. Attrition of penetrators at the target area by long and short range anti-aircraft fire is calculated using a multiple shot binomial equation of the form $\Delta T = T(1-(-P_k)^S)$. Detection is included within P_k. Attrition of suppressor aircraft by long range anti-aircraft fire is an input table look-up. S is the number of sites protecting the point target or battalion area. The equation for $B^{(4)}{}_{km}$ at the top of page 183, Volume I, "A User's Guide," is an error. The terms $(1-q_{t2km})$ and q_{t2km} should be exchanged.

Egress attrition due to randomly deployed ADA is calculated in the same manner as ingress attrition. Except for the effects of previous suppression, the same percentage of available aircraft is destroyed during egress as during ingress.

a. Inputs by User

- Probability of kill during ingress or egress by site type, by target aircraft type, by mission.
- Number of sites defending point targets, by site type.
- Probability an attack or escort aircraft is killed by an individual site, by site type, by target aircraft type, by mission.
- The number of suppressor aircraft destroyed in the duel with a SAM site.

b. Inputs Generated by the Model

- Number and size of penetrator groups, by aircraft type, by mission.

c. Outputs

- Number of penetrator aircraft killed by type, by mission.

d. Assumptions

- Ground-to-air defense is a sector phenomenon.
- Area sites in a sector and sites at a point can fire at a fixed fraction of penetrators. Saturation causes no variation in the ability to fire.
- Sites are uncoordinated so redundant kills occur.

6. Discussion

In all models except CEM, a deep-penetrating aircraft can encounter area-deployed and point-deployed ADA of at least two distinct types. The CEM treatment in contrast allows the penetrator to encounter only one type notional defense at only one location. In all models, CAS sorties encounter ADA only once, not twice, but as before, CEM treats one ADA type while the others treat two or more.

a. Coordination

As in all the attrition encounters, IDAGAM allows the user to select among several attrition equation forms for both AAG and SAM fire. With this selection one makes assumptions as to acquisition and fire coordination. VECTOR and LULEJIAN do not allow this option in attrition forms. VECTOR assumes a multiple engagement binomial form implying a constant saturation level. LULEJIAN uses an area coverage model with single engagement allowed for area-deployed ADA. All point-deployed ADA engage penetrators. SAM sites may fire more than one missile, but the number fired is a user input and therefore predetermined.[1]

b. Corridor Penertation

VECTOR and IDAGAM do not model corridor penetration. LULEJIAN treats it superficially by assuming that a doubling of the number of corridors doubles the capability of the ADA, an assumption which is only true at saturated levels.

c. Abortion

None of the models treat the likelihood that a penetrator which is engaged by SAMs will abort the mission. In general, no model treats the ability of ADA to influence the effectiveness of air munitions delivery.

d. Flight Profile

None of the models varies the capability of ADA depending on the flight profile. Since, however, each model accepts inputs describing the capability of ADA by shooter type, by target type, and by mission it would be possible to adjust input

[1]Actually, a set number is assumed fired for calculating aircraft kills. Then after the fact, the number actually fired is calculated using: $\frac{\text{Number of kills}}{P_k}$.

capabilities so as to approximate different profiles. This procedure would also require adjustment of penetrator capabilities in terms of range, payload and munition effectiveness parameters. The procedure might be ponderous.

e. ECCM

ECCM is not modeled.

f. Misdirected Fire

In none of the models are friendly aircraft inadvertently subject to friendly ADA fire.

J. AIR DEFENSE ARTILLERY SUPPRESSION

1. Topic

In this section, the manner in which attacking aircraft suppress the opposing air defense artillery (ADA), consisting of both surface-to-air missiles (SAM) and anti-aircraft guns (AAG), will be discussed. Any capability to model ECM is represented in this section.

2. CEM

The CEM model allows the destructive attack of SAM sites by an input fraction of counter air (CA) sorties. The effect of this attrition to SAMs is felt in subsequent periods rather than the current period. The number of SAM sites destroyed is calculated by multiplying the per-sortie capability of the aircraft by the number of sorties.

a. Inputs by User

- Fraction of CA sorties allocated to attack of SAM sites.
- Number of SAM fire units destroyed per attacking aircraft sortie.

b. Inputs Generated by the Model

- Number of CA sorties
- Number of SAM fire units.

c. Outputs

- Number of SAM fire units destroyed.

d. Assumptions

- Suppression is a delayed attrition phenomenon.
- Detection of SAMs by suppressors is perfect.
- Attack coordination is perfect.

- No destruction or suppression of divisional air defenses is possible.

3. IDAGAM

In IDAGAM, suppression is modeled as an attrition phenomenon. As in other interactions, the form of the attrition equation may be selected by user option. Suppression can be directed against the one type of SAM and the one type of antiaircraft gun (AAG) in the forward sectors and at each airbase. An input percentage of the primary mission aircraft is designated for suppression; however, this percentage will be linearly reduced if the number of SAM or AAG sites is below an input level. Below a threshold input level of SAM and AAG sites, no aircraft are designated for suppression.

a. Inputs by User

- Probabilities of detection and kill of SAMs and AAG, by aircraft type.
- Percentage allocations to SAM and AAG suppression.
- Number of SAM and AAG sites below which no suppression is to occur.

b. Inputs Generated by the Model

- Number of suppressor missions, by aircraft type, by target airbase or sector.
- Current SAM and AAG inventories.

c. Outputs

- Number of SAMs and AAGs destroyed.

d. Assumptions

- Suppression is an attrition mechanism. Suppression is permanent.
- The degree of suppression is related in a linear or binomial form to the number of aircraft assigned to suppression missions.

4. LULEJIAN

Suppression aircraft are assigned to missions in the same proportions as the strike aircraft which they are assisting. These suppressors interact with two classes of air defenses, the area-deployed and the point-deployed defenses. The attack of area-deployed systems by fly-by suppressor aircraft is temporary 24 hour suppression, as opposed to an attrition phenomenon. Each aircraft is given a capability to suppress an area of SAMs and an area of AAG. Percentage suppression is calculated by an exponential expression of the form 1-exp (-T/R) where T is the summed area suppression potential and R is the area of SAM or AAG deployment. Point-deployed SAM and AAG in the interdiction target areas are attacked with both suppressive and destructive weapons. Area sites are attacked by suppressors accompanying interdiction aircraft targeted against vehicles in the LOCs. In fly-by suppression, the relative capability against SAM and AAG could vary. In target area suppression, the relative capability against each is fixed. The limitation pertaining to target area suppression assures that SAM and AAG are attrited in fixed proportions to one another. The fractions of point-deployed sites suppressed and destroyed are calculated using an exponential of the form 1-exp (-T/US) where T is a summed potential to destroy sites, U is the number of battalions at the point and S is the number of sites per battalion.

a. Inputs by User

- Capabilities of fly-by aircraft to suppress SAMs and AAGs by aircraft type.
- Capabilities of point-attack aircraft to suppress and fractionally destroy ADA sites by aircraft type. ADA sites are composed of fixed fractions of SAMs and AAGs.
- Number of sites per ADA battalion.
- Preference levels for use in assigning particular types of aircraft to suppression missions.

b. Inputs Generated by the Model

- Number of suppression sorties, by point-attack mission.
- Number of ADA sites at each target.
- Area associated with deployed SAM and AAG sites.

c. Outputs

- Number of area-deployed SAM and AAG suppressed.
- Number of point-deployed ADA battalions suppressed and deployed.

d. Assumptions

- Specific suppression aircraft assignments are independent of the density of ADA sites in the particular target areas.
- ADA sites have a fixed mix of AAG and SAMs.
- An area-effects mode is used in fly-by suppression of randomly deployed sites.
- Point attack with perfect acquisition is used in the attack of ADA sites at interdiction targets.
- Redundant suppression and kills occur.

5. VECTOR

In the VECTOR model, suppression is a principal mission rather than being a percentage of another mission. Based on input, such missions can either make a suppressed site unavailable for a number of days or can destroy the site.

The number of long and short-range sites suppressed is determined by multiplying the number of suppressor groups by the surviving group size by the kill or suppression capability of each aircraft.

The surviving group size is the original input-specified size reduced by the percentage of aircraft engaged (not necessarily destroyed) by interceptors. In addition, the percentage of aircraft destroyed by short and long range ADA weapons during the penetration and the suppressive attack reduces the group

size. Detection of ADA/sites by suppressor aircraft is assumed to be perfect.

a. Inputs by User

- The probability of kill or suppression and the period of suppression, per aircraft type, per mission type, per suppression target.
- The initial aircraft group size, per aircraft type, per mission type.

b. Inputs Generated by the Model

- Surviving suppressor sorties.
- Short and long range ADA inventory, by sector.

c. Outputs

- Short and long range ADA sites suppressed and destroyed, by sector.

d. Assumptions

- Suppression is a point-to-point phenomenon and is linearly proportional to the ratio of suppressors to sites.
- Suppression attacks are perfectly coordinated.
- Suppressors will detect targets if targets are present.

6. Discussion

a. Suppression vs Destruction

A major difference between models is in the differentiation between suppressive attacks and destructive attacks. In two models, CEM and IDAGAM, the attack of ADA is purely destructive rather than suppressive and destructive. IDAGAM assumes that the site attacked is destroyed immediately; CEM assumes that the site is effective for this period and destroyed in subsequent periods. VECTOR and LULEJIAN assume that both

temporary suppression and fractional destruction can occur. Since electronic counter-measures can make ADA ineffective but do not destroy the sites, the VECTOR/LULEJIAN assumption appears better.

b. Resolution

All models except CEM treat suppression of SAM and AAG separately. In LULEJIAN however, SAMs and AAG must be destroyed in fixed proportions to one another. This is not the case in LULEJIAN fly-by suppression.

c. Command and Control

As was the case in air-to-air combat and airborne attack, each model makes slightly different assumptions concerning target acquisition and attack coordination. These assumptions have been listed in the particular model paragraphs. In IDAGAM the mathematical form of the engagements may vary depending on user option. In VECTOR, CEM and LULEJIAN the attrition form, hence the basic coordination structure, is fixed.

d. Requirement

Only IDAGAM contains internal logic to determine a need for suppression missions. The number of suppression sorties, as a percent of the escorted mission sorties, will vary between a user maximum and zero, depending upon the number of sites to be suppressed. In VECTOR, logic for allocating aircraft to the suppression mission is input as tactical decision rules. The number of sites to be suppressed can be a part of the decision criteria. In the other models, the amount of effort the model allocates to suppression is independent of the number of sites to be suppressed.

K. FEBA MOVEMENT

1. CEM

In CEM, FEBA movement is determined by comparing the existing force ratio with input threshold values. For a given type of activity and terrain, a FEBA movement rate is associated with each force ratio threshold value.

As with attrition, FEBA movement computations are made at the subsector level; that is, at a level where elements of no more than one basic unit are present on each side of the FEBA. The force ratios formed at subsector level to determine FEBA movement are computed expressly for that purpose and are different from the ratios used to assess attrition. That is, a modified set of firepower scores is used in forming each ratio.

For attrition calculations, basic directed firepower scores are modified to account for supply status and terrain. For FEBA movement calculations, these modified firepower scores are again modified to account in a simple way for the composition of the opposing force. For example, the total anti-tank firepower of the Blue force is multiplied by the fraction of the total Red ground firepower which is attributable to tanks. The Blue anti-light armor and anti-personnel firepower scores are similarly modified, as are all three types of Red firepower scores. After these modifications, total scores for Blue and Red are used to form the force ratio for FEBA movement.

Since no combat interactions occur on flanks, methods are provided in the model to prevent unrealistically long exposed flanks at each subsector. A defending Blue brigade (or Red division) will withdraw a subsector so that, at the most, only one flank of that subsector is exposed. If a Blue brigade (or Red division) has two exposed flanks, it must meet stricter criteria to be able to attack than does a similar unit without the exposed flanks. Also, the unit with the exposed flanks

is restricted from advancing even if the attack is successful. Similarly, within an attacking brigade (or Red division) any subsector which has no flank length less than the subsector width is prevented from advancing. Finally, after all the other criteria pertaining to FEBA smoothing have been met, the FEBA position of each subsector is arbitrarily moved, in either direction, so that it is no more than an input distance, L, from the FEBA position of the adjacent subsector. The northernmost subsector, in a theater where the FEBA moves east-west, is used as the starting, reference point in this final smoothing.

a. Inputs by User

- FEBA movement rates (per division cycle--typically 12 hours). There are 80 rates for each side, to account for variations in activities, terrain, and engagement results. There are 4 types of activities: attack-delay; attack-prepared defense; attack-hasty defense; meeting engagement. Terrain is classified into 3 general types, with a fourth type representing a major obstacle. Possible engagement outcomes are: overwhelming loss, loss, draw, win, and overwhelming win. Nominal movement rates are reduced when Blue is able to prepare a barrier and employ it in a delaying action; Red does not have this capability.
- Threshold force ratio values to determine which of 5 engagement outcomes takes place. (Possible outcomes are listed immediately above.)

b. Inputs Generated by the Model

- Current anti-tank, anti-light armor, and anti-personnel firepower scores for each side at each subsector. These scores are modified to account for supply status and terrain.
- The type of terrain in the vicinity of the FEBA location in each subsector.
- Designation of the activity taking place in each subsector.

c. Outputs

- The FEBA position at each subsector.
- Lengths of exposed flanks at each subsector.

d. Assumptions

- The variables which influence FEBA movement rates are adequately described by the different activities, terrain types, and possible engagement outcomes which are listed in paragraph a. above.
- FEBA movement rates are independent of the type of units involved, and in particular are independent of the relative mobility of units.
- The decision rules and FEBA smoothing techniques described above are an adequate substitute for explicit representation of maneuver and of combat interactions across flanks.

2. IDAGAM

In IDAGAM, FEBA movement is a function of force ratio, type of defensive posture, type of terrain, mobility of the attacker's divisions, and use of air forces. Movement rates are input by the user as piecewise linear functions of force ratio. Separate functions are input for each combination of terrain and posture. The mobility of attacking units is accounted for by multiplicative mobility factors which are user inputs. Mobility factors less than one cause a reduction in the movement rates obtained from the input functions; factors greater than one increase the movement rates.

FEBA movement in IDAGAM is computed at sector level. Since more than one type of division is likely to be present in a sector, methods are provided for determining the overall mobility factor for the sector force. The user may select one of four methods:

(1) Set the sector mobility factor to be one, thereby using without modification the input FEBA movement rates.

(2) Set the sector mobility equal to the factor for the sector division with the least mobility.

(3) Set the sector mobility factor equal to the factor for the sector division with the greatest mobility.

(4) Use a weighted average of the mobility factors for all the divisions in the sector, taking into account the relative sizes of the divisions.

At the model user's option, the FEBA movement rates which have been modified to account for the attacker's ground mobility can be further modified to account for the vastly greater mobility of tactical air forces. When the attacker has both a ground and air advantage over the defender, the ability to concentrate combat air support in particular locations in the sector tends to cause the FEBA movement rate to increase. The detailed computations are too complex and lengthy for inclusion in this report; the interested reader is referred to the model documentation (pages 75f, Volume 1, IDA Report R-199). In no case will the computations which are made to account for the mobility of air forces cause the FEBA movement rate to be less than it would be without the calculations.

After FEBA movement has been determined for each sector, smoothing is accomplished according to input front-to-flank criteria. If both flanks of the attacker are exposed, the total length of exposed flanks on both sides is divided by 2 to obtain the average length. When the ratio of sector width to average flank length is less than an input value, the FEBA in that sector is pulled back until the input criterion is satisfied. If only one flank is exposed, the attacker is not pulled back.

After exposed flanks for the attacker are examined, and necessary adjustments are made, the exposed flanks of the defender are checked. In this case, the length of each exposed flank is checked individually, and then the sum of the two lengths. If in either of the three tests the input front-to-flank criteria

are not met, the defender will be pulled back. Flanks at the extreme left and right of the theater are not considered exposed for either side.

For both the attacker and defender, the exposed flank lengths may be modified prior to the above tests by means of an "edge factor." The actual length of exposed flank is multiplied by the edge factor to account for terrain features and other restrictions to mobility. It is assumed that these restrictions would tend to limit the effects of the flank exposure. With edge factors less than one, the restricted mobility is represented by using less than the actual length of exposed flanks to calculate the front-to-flank ratio.

The values of opposing forces which are used to form force ratios for FEBA movement are computed in the same way as the values used in attrition calculations. The optional method of computation chosen for attrition calculations, e.g., antipotential potential, will also be used for FEBA movement.

a. Inputs by the User

- FEBA movement rates as a function of force ratio. Separate piecewise linear functions are input for each side, for each combaination of terrain and defensive posture. Typically, 4 different defensive postures and 3 terrain types are represented.
- Mobility factors for each type of division, for each side. Movement rates input by the user are multiplied by the mobility factors to obtain actual rates. A mobility factor of one is standard.
- The designation of the method to be used to derive sector mobility factors from the mobility factors of individual diviisions in the sector. The four methods available are given in the description above.
- The relative size of each type of division in the sector, for computing the weighted average mobility factor. The relative sizes are input as fractions, with one as standard.
- The minimum width of the area within a sector in which

each side can effectively concentrate his air forces to help the ground forces create and hold a salient.

- The minimum average ratio of front width to average exposed flank length which can be maintained in a sector by the attacker with both flanks exposed, for each side. If the average front-to-flank ratio in a sector is less than this input value, the sector will be pulled back so that the criterion is met.
- The minimum ratio of front width to the length of either exposed flank which can be sustained by the defender, for each side. When the ratio is lower than this input, the defender pulls back.
- The minimum ratio of front width to the average length of both exposed flanks of the defender. If the average front-to-flank ratio is less than this input value, the defender will pull back, even though criteria pertaining to each exposed flank separately may have been satisfied.
- Edge factors, to account for decreased mobilily across exposed flanks. The flank lengths used in calculating front-to-flank ratios are decreased by multiplying actual lengths by the edge factors. The edge factors are input by terrain interval within each sector.

b. Inputs Generated by the Model

- Force ratio in each sector.
- Designation of the attacker in each sector, and the posture of the defender.
- The sector width and type of terrain in each sector at the location where ground combat occurs.
- Designation of the terrain interval in each sector where exposed flanks are located. This is to ascertain which input edge factor should be used for front-to-flank calculations.
- Inventory of divisions in each sector, by side and type.

c. Outputs

- The FEBA position in each sector.
- Front-to-flank ratios in each sector.

d. Assumptions

- The FEBA movement rate is a function of force ratio, terrain type, defensive posture, and the relative mobility of the attacker.
- The effects of combat across sector (corps) flanks, or the threat of such combat, are dependent on front-to-flank ratios and can be accounted for by FEBA smoothing.
- When the attacker has a ground advantage, his ability to concentrate air attacks in specific locations affects FEBA movement. The movement can be greater when air attacks are concentrated than when they are allocated evenly across a sector front.

3. LULEJIAN

FEBA movement in the LULEJIAN model is computed dynamically, as a function of the attrition of major elements of both sides. A fundamental assumption incorporated in the model is that each side has the ability to manage attrition by trading ground area for survivability. For each sector, an iterative procedure is used to calculate the fractional attrition of committed forces and the FEBA movement, so that the ratio of actual attrition to acceptable attrition is directly proportional to the ratio of actual FEBA movement to maximum FEBA movement. The equations used, which apply to a single model time period, are in the following forms.

For the attacker:

$$\frac{\Delta S_a}{S_{max}} = 1 - \frac{\Delta Xa}{C_a X_a}$$

where:

- ΔS_a = actual FEBA movement.
- S_{max} = maximum FEBA movement of the attacker.
- ΔX_a = actual attrition of the attacking element.
- C_a = the fractional attrition of the attacking element below which the element will continue to advance.

- X_a = the number of attacking elements which participate in the attack.

For the defender:

$$\frac{\Delta S_d}{S_{max}} = \frac{\Delta X_d}{C_x X_d} - 1$$

where:

- ΔS_d = actual FEBA movement.
- S_{max} = maximum FEBA movement of the attacker, per time period.
- ΔX_d = actual attrition of the defending element.
- C_x = the fractional attrition of the defending element above which the element will retreat.
- X_d = the number of defending elements which participate

The equations are applied to 3 elements on each side: Infantry, tanks, and APCs. They are solved simultaneously, with the constraint that the FEBA movement is the same for every element on both sides. (In the equations, FEBA movement in the direction of the attacker's objective is considered positive.)

The maximum FEBA movements used in the equations are derived from maximum movement rates input by the user. The modifications to the input rates are based on the width of the sector and the total "search widths" of the sector attacker. The rate of forward movement by the attacker is limited by his ability to search for defending elements throughout the entire area which he is acquiring. Basic threshold attrition rates, C_a and C_d, are input, and are modified according to the average casualty history of the unit. The actual attrition rates are computed using the maneuver unit interactions equations.

There are no provisions, as such, for FEBA smoothing, that is, to adjust sector FEBA positions to bring them closer to a mean theater FEBA position. The model accounts for the absence of interactions across exposed flanks at sector boundaries by

means of its determination of the daily activities of the forces in each sector. User-input critical flank lengths are considered in the decisions to attack, defend or delay.

a. User Inputs

- Maximum, unopposed movement rate by side, type of unit, and type of terrain.
- The fractional attrition below which an attacking unit will continue to advance, by side and type of unit.
- The fractional attrition above which a defending unit will give up its position, by side and type of unit.

b. Inputs Generated by the Model

The internal inputs to this functional area are used in iterative calculations relating FEBA movement, attrition, the capability of units to find opposing units, and the commitment of units to combat. Thus, although they are inputs to the functional area of FEBA movement, their values are in turn derived from the calculations in this area.

- Number of units committed to combat, by side and type.
- Maximum movement rate of attacking units, considering their ability to search the area of operations for opposing forces, by type of unit.
- Threshold attrition rates, which take into account casualty history, by side and type of unit.
- Actual attrition experienced, by side and type of unit.

c. Outputs

- FEBA position in each sector.
- Total area gained or lost by the theater attacker. Total area gained is the payoff value used in generating "optimized" allocations of certain resources.

d. Assumptions

- There is a direct, linear relationship between attrition levels and FEBA movement, both for the attacker and

and defender. The equation for this relationship is given in the description above.

- Within a sector, all units for a given side advance or fall back at the same rate, regardless of unit type.
- For a given side the number of units committed to combat tends to increase as the side becomes less successful, up to some input limit. The equation which describes this relationship is as follows for defending infantry:

$$B_{X_{de}} = \{F_o + (F_{max} - F_o)\ 1.582\ (1 - e^{-\Delta S/S_{max}})\}\ B_{xd}$$

where:

$B_{X_{de}}$ = the number of defending infantry battalions committed to the battle.

B_{xd} = the total number of defending infantry battalions in the sector.

F_o = the fraction of the defending infantry battalions committed when there is no FEBA movement.

F_{max} = the fraction of the defending infantry battalions on line at maximum FEBA movement.

ΔS = the actual FEBA movement.

S_{max} = the maximum FEBA movement for the given situation.

Equations of similar form are used for defending mechanized and tank battalions and for each type of attacking battalion.

- For purposes of computing FEBA movement, the effects of important terrain features such as rivers may be accounted for indirectly. For example, one of the three classes of terrain in the model might be assumed to encompass the feature.
- The effects upon FEBA movement of combat interactions across sector boundaries (corps flanks) can be indirectly represented through the use of appropriate logic to determine combat activities. Flank lengths are considered when decisions to attack, defend, or delay are made in each sector.

4. VECTOR

FEBA movement in VECTOR-1 occurs at each battalion area. Tactical decision rules are used to decide whether the forces of either or both sides in the battalion area desire to advance, and then to decide which of them actually makes an attack. They

are also used to determine the defender's response to an attack. If the attack is against a hasty defense, the ground combat submodel is used to determine the winner. If the attacker wins, FEBA movement occurs in the direction of the attack. If the defender wins, no FEBA movement will take place. For other activities, i.e., advance/delay, pursuit/withdrawal, or an attack against a barrier or terrain feature, the FEBA will move in the direction of the attack. If neither side attempts to advance, then no FEBA movement occurs.

The amount of FEBA movement is determined from input lookup tables. This amount may be modified on the basis of any state variable(s) by means of the tactical decision rules.

The FEBA positions of the individual battalion areas may be modified, or "smoothed" to make the FEBA of an entire sector a straight line, or more nearly a straight line. This smoothing is to account for the unrealism introduced by the lack of interactions on battalion flanks. Similarly, the positions, or average positions, of the FEBA in the various sectors may be smoothed to make the FEBA of the theater more nearly a straight line. This is to account for the absence of force interactions across sector boundaries. One method for smoothing the FEBA is incorporated into the model program. It will restrict the total deviation of battalion area FEBA positions from the sector mean position and the deviation of the sector mean positions from the theater-wide mean position in accord with limits set by tactical decision rules or directly by the user. If the user does not desire to use this smoothing scheme, any logic considered appropriate may be adopted through the use of the tactical decision rules.

a. <u>User Inputs</u>

- The FEBA movement rates for forces in a battalion area which are not involved in a terrain feature activity. The rates are indexed as follows:

  (1) Type of activity
  - Blue (Red) pursuit, Red (Blue) withdrawal
  - Blue (Red) advance, Red (Blue) delay
  - Blue (Red) defense, Red (Blue) assault
  - Relative inaction (movement is normally considered zero)

  (2) Minefield considerations
  - No minefield
  - Minefield, cross without clearing
  - Minefield, cross with clearing
  - Minefield, bypass

  (3) Terrain classification - There are 5 classes of terrain trafficability.

- The FEBA movement distance per simulated time period for an activity at a terrain feature. Terrain feature activities are:

  - Blue (Red) bypassing an urban area
  - Blue (Red) bypassing a user-defined terrain feature
  - Blue (Red) crossing an urban area
  - Blue (Red) crossing a user-defined terrain feature
  - Blue (Red) crossing a river

- A factor to determine the difference in distance between the mean sector FEBA and a battalion area FEBA that must be exceeded in order to pull stalled forces across a terrain feature. This required difference is obtained by multiplying the factor by the input distance which can be traversed across the feature in a model time period. This factor may be set at a very large value if the pulling forward effect is not desired.

- The maximum distance a battalion area may be from the mean FEBA position in its sector, and the maximum distance a sector mean FEBA position may be from the theater mean FEBA. These distances are used if the

programmed method of FEBA smoothing is employed by the user. Other smoothing methods may be designed by the user and implemented through the tactical decision rules.

b. Inputs Generated by the Model

- Designation of the activity taking place in each battalion area.
- Information as to the terrain classification and the existence of minefields and terrain features at each battalion area.
- The outcome (winner and loser) of each battalion-level attack/defense activity.

c. Outputs

- The amount of adjustment to battalion area FEBA positions and mean sector FEBA positions necessary to achieve the desired degree of FEBA smoothing.
- For each time period, the FEBA position of each battalion area, mean sector FEBA positions, and the mean theater FEBA positions. All positions are given in terms of distances from a common reference line.

d. Assumptions

- The descriptors used to index the input FEBA movement rates are adequate to differentiate among the factors affecting movement. (This assumption holds if the basic model structure is used. Other factors may be considered through the use of tactical decision rules.)
- The lack of explicit combat interactions between adjacent battalion areas and adjacent sectors may be overcome through the use of FEBA smoothing techniques.
- FEBA movement rates at battalion level may adequately be extrapolated to determine overall sector and theater FEBA movement through the use of appropriate smoothing techniques.

5. DISCUSSION

There are significant differences among the models in two aspects of the FEBA movement. These are (1) the command level at which FEBA locations are accounted for and moved, and (2) the way in which basic input movement rates are converted to daily FEBA movements in the model.

Each of the models keeps track of FEBA locations and movements at the command level, or force size, it uses in attrition calculations. In this respect, CEM and VECTOR, which determine attrition and FEBA movement at the brigade or lower level, differ markedly from IDAGAM and LULEJIAN, which make these determinations at sector, i.e., corps, level. In CEM and VECTOR it is necessary to relate in some way the individual FEBA positions to the overall situation in the corps, and then the theater. None of the models allows combat across basic unit flanks, whether those units are large or small. Therefore, other methods are necessary to "smooth" the FEBA and prevent unrealistic differences among individual FEBA positions. The smoothing logic is built into CEM, with numerical criteria input by the user. Built-in logic is also available in VECTOR, but it can be overridden by input logic provided by the user as tactical decision rules. In neither model is there an attempt to represent the physical processes which relate individual unit locations to the status of the entire theater force.

Similar problems in relating the FEBA positions of individual force elements to each other arise in IDAGAM and LULEJIAN, but they are explicit in the model only at a higher level. Since FEBA locations are determined in terms of corps-sized organizations occupying an entire sector, there is no need for model logic to adjust positions below that level. Logic is present in IDAGAM to make adjustments to sector FEBA positions so that they are sensible in relation to each other. LULEJIAN has no logic for direct adjustment of sector FEBA positions,

but the rules for selection of sector activities tend to prevent unrealistically long exposed, but invulnerable, flanks.

The representation by IDAGAM and LULEJIAN of the FEBA of an entire sector as a straight line does not, of course, reflect the conditions which are expected on a real battlefield. Within a corps, it is certain that some divisions or smaller units will at times occupy positions behind or ahead of their neighbors. A single sector FEBA must, therefore, be regarded as a kind of average position for the corps. All of the relationships of smaller units, and even individual weapons, to the overall corps must of necessity be imbedded within the performance capabilities input to the model.

The requirement to relate properly the FEBA positions of smaller units to the corps as a whole is explicit in CEM and VECTOR, since it is addressed within those models. In IDAGAM and LULEJIAN, the relationships must be addressed outside the model, using assumptions which are consistent with the model and with the analysis being performed.

Three of the models, CEM, IDAGAM, and VECTOR, derive the amount of FEBA movement from input lookup tables. In all three, input rates can vary according to terrain, force activity, and either force ratio or the outcome of engagements. In IDAGAM and VECTOR the type of attacking unit and its inherent mobility are also considered. Also, IDAGAM allows the modification of rates to account for concentrated air support. Except for CEM's inability to differentiate among types of units, the important differences among the three are related to their basic interaction mechanisms. Each of them allows for adequate variations in the parameters which control FEBA movement, and none of them attempts to model the movement process itself. Any desired source of basic movement rates may be input by the user; rates may be based on military judgment, historical data, or higher-resolution modeling. The relation between input

rates and the FEBA movement output by the models can easily be seen by the using analyst.

The LULEJIAN model is unique in its computation of the amount of FEBA movement. Movement rates, as such, are input as a function of terrain type only, and are taken to be maximum rates, not averages. The rates are modified in the model computations according to the ability of attacking units, by type, to search out the area of operations for enemy forces. Units with greater "search potentials" can attain higher maximum movement rates than those with lesser search potentials. Also, as the number of units available to search out a sector increases, the maximum attainable movement rates tend to increase. In no case, for a given type of terrain, does the maximum attainable rate exceed the absolute maximum rate which was input. The actual movement rate is some fraction, between -0.5 and 1.0, of the maximum attainable rate, and is a direct function of the level of attrition being experienced.

All the factors which are considered in determining FEBA movement in the other three models are also considered by LULEJIAN. In addition, it is the only one which attempts to model the movement process, albeit in an aggregated way. The assumptions associated with the LULEJIAN method are plausible, given the level of aggregation, but are certainly unproven. The advantage with LULEJIAN is that many of the assumptions necessary to calculate FEBA movement are an explicit part of the model and not an implicit, possibly invisible part of a set of lookup tables. Conversely, it is more difficult to use detailed historical movement data in the LULEJIAN model than in the other three. It is also more difficult to analyze the reasons for the movement rates which are being observed.

L. LOGISTICS: STRUCTURE, CONSUMPTION AND AVAILABILITY

1. CEM

The model represents theater stockage levels and resupply on an aggregated basis. It categorizes supplies as POL, ammunition, and "all other" supplies for combat units. Associated with this are the expenditure and replacement of major weapon systems: tanks, APCs, helicopters, anti-tank weapons, and mortars. Personnel replacements, similarly associated, are treated elsewhere. For each maneuver unit, a record is kept of the amount (in tons) of each type of supplies on hand, the numbers of each type of weapon system, and personnel strength. As new quantities arrive the unit record is up-dated. This record is kept for Blue brigades and Red divisions for each time period represented by theater and division cycles.

Supplies for combat units are introduced at the theater level and separated into theater pools for each type of supply. From the theater pools the resources are delivered to the brigades and cavalry units (Blue) and divisions (Red) during the ensuing division cycles on the basis of need. Quantities of supplies available may vary each theater cycle as desired by the model user. Supplies are consumed based on intensity of combat and force capability. A comparison is made at the division cycle of the levels of expected supply consumption, by type, for the planned engagement and the amount of supplies, by type, on hand. Based on user input for the number of days supply level desired (which is input on the basis of division cycles), the supply module will compare actual supplies on hand vs. expected usage of supplies for the particular engagement. If the amount of a given type of supply to be expended would cause the level remaining to go below an input safety level, conservation of supplies occurs. This can, at the option of the user, degrade firepower during the engagement.

The degree of degradation is input by the user. Separate expressions are used to relate conservation to firepower degradation for POL and other supplies, and by type weapon.

a. Inputs by User

- TOE equipment authorizations for combat units, by type of unit and type of equipment.
- Initial amounts of supplies and equipment, by type, on hand for each combat unit.
- Supply consumption rates, by type of supply, type of engagement and type of unit. For some weapons, the rates are input by weapon type, not unit type. The rates are in tons per division cycle.
- Rate of arrival of supplies and equipment into the theater pools, for each theater cycle.
- Factors to be used in computing the degradation of firepower due to supply shortages.
- Factors to determine safety levels for each type of supply.

b. Inputs Generated by the Model

- Designation of the estimated and the actual type of engagement for each combat unit during each division cycle.
- Quantity of equipment, by type, lost in combat by each unit during each division cycle.
- Quantities of supplies and equipment, by type, allocated and available for issue to each combat unit, per theater cycle.

c. Output

- Quantities of supplies and equipment, by type, issued to each combat unit, by division cycle.
- Updated quantities of supplies and equipment on hand in each unit.
- The amount of firepower degradation attributable to supply shortages, for each combat unit.

d. Assumptions

- For theater-level combat analysis, supplies may be aggregated into the following three categories: POL, ammunition, and all other supplies.
- Supplies and equipment are allocated directly from theater pools to combat units, based on need.
- The effect, if any, of supply shortages is to degrade the firepower of combat units.

2. IDAGAM

The model plays only one aggregated type of supplies. It can include food, ammunition, and fuel for both ground and air forces. The unit of measure for supplies is tons. The consumption rates of supplies are input as tons used by each person (by type), each ground weapon (by type), and each aircraft (by type) per time period. (For personnel and ground weapons, this consumption rate is also a function of posture.) The model similarly plays the resupply of the weapons which it represents. The attrition of weapons during combat determines the requirements for replacements. Since the allocation of replacement weapons is closely coordinated with the allocation of replacement personnel, the details of the replacement weapons allocation scheme are covered in section O of this appendix, "Personnel Replacements."

The model permits location of supplies in sectors, regions, and the communications zone. Supplies in sectors are used by the divisions in these sectors. Supplies in regions are in pools used to provide supplies to the divisions not in combat which are located there, and in pools which provide supplies to the divisions in sectors. Similarly, supplies in the communications zone form the supply pool which feeds supplies into regions and the pool which provides supplies to the divisions located in the communications zone.

Within regions and within the COMMZ, supplies are moved

between pools supporting forward areas and pools supporting units in the regions and COMMZ, if either of the pools has more supplies than needed.

Supplies are allocated from COMMZ to regions, from regions to sectors, and from sectors to divisions in sectors based upon need. If the amount of supplies available at any level is inadequate to meet the demands at lower levels, the available supplies are prorated according to demand. ("Demand" is the difference between the supply level authorized and that on hand.)

When the level of supplies is less than the input minimum level in any combat unit, the effectiveness of that unit is degraded. The degree of degradation is input as an effectiveness factor, less than one, which is a function of the days of supply on hand. In general, the normal effectiveness of each weapon is multiplied by this factor to determine its effectiveness when there are inadequate supplies.

The results of shortages of weapons in ground combat units are reflected directly in the attrition calculations. The attrition which can be inflicted by a force is a function of the number and type of weapons which can actually be employed each day. Similarly, SAMs are considered to be separate weapons instead of ammunition, and shortages of SAMs are also reflected directly in the attrition equations.

Aircraft supplies, in tons, are obtained by air forces from COMMZ supply pools, and if necessary from region pools. Input consumption rates, by aircraft and mission type, are used to calculate daily demand. If there are inadequate supplies to support all planned sorties, the number of sorties is reduced in proportion to the shortage of supplies.

Supplies in regional pools can be destroyed by aircraft, and supplies in sector pools can be destroyed by both aircraft and ground weapons.

a. Inputs by User

- Desired levels of supply in sectors, regions and the COMMZ, in terms of days of supply.
- Initial amounts of supplies on hand in each sector, region and COMMZ, in tons.
- Supply consumption rates for ground forces and aircraft.
- Effectiveness degradation factors for combat units, as a function of the days of supply on hand.
- Combat unit TOE equipment and personnel authorizations, by type of unit.
- Initial equipment inventories and personnel strength for each type of combat unit, by sector, region and COMMZ.
- Initial number of SAMs on hand, by location.

b. Inputs Generated by the Model

- The amount of supplies delivered each day to supply pools at sector, region and COMMZ.
- Daily updated inventories of combat unit equipment and personnel, by type of unit and by location, i.e., sector, region, COMMZ. (This input is generated within this supply functional area, and later used by it.)
- Number of planned daily aircraft sorties, by location.
- Number of SAMs delivered each day, by location.
- Number of replacement items of equipment delivered each day to each type of combat unit, by location.
- The amounts of supplies in supply pools which are destroyed by aircraft and ground weapons, by pool location.

c. Outputs

- Number of days of supply on hand in supply pools at sector, region and COMMZ levels. This and other daily updates reflect consumption, attrition and resupply which have occurred since the previous day.
- Updated inventories of equipment in each type of unit, by location.
- Updated SAM inventories, by location.

- Effectiveness degradation of combat units, by type and location, if the level of supplies on hand is inadequate.
- Fractional degradation of the numbers of planned aircraft sorties which can be flown, by location, if adequate amounts of supplies are unavailable.

d. <u>Assumptions</u>

- The supply aspects of combat may be adequately represented for theater-level analysis by considering a single aggregated category of supplies, which is used by both ground and air forces.
- The same average effects of supply shortages apply to all ground combat units of a given type in a particular location. That is, all units of the same type in the same sector, region or COMMZ are assumed to be in exactly the same, average condition.
- Supply consumption in ground units is a function of the number of personnel and the numbers and types of equipment on hand.
- Supply consumption of air forces is a function of the number of sorties flown.
- Supplies located in the COMMZ or in ports are not subject to air attack.
- Only those supplies located in sector pools are subject to attack by ground weapons.
- As the amount of available supplies falls below some critical level, the ability of a ground force to inflict attrition on its opponent is degraded. The degree of degradation is a direct user input.
- A shortage of supplies for air operations is reflected by a proportional reduction in the sorties which may be flown. Only the number of sorties which can be supported by the available supplies will be flown. There is no degradation of the effectiveness of those aircraft which are able to operate.

3. LULEJIAN

Arrival and Transport of Resources

The LULEJIAN logistics system consists of a theater depot or port with a designated input capacity, a transportation network (including both a ground network and airlift), and stockpiles of resources within the theater. The following types of resources may enter the theater through the port: infantry, mechanized infantry and tank battalions for each national participant; SAM battalions; artillery battalions; individual infantry, APC, tank and SAM replacements; individual tactical aircraft, helicopters and artillery pieces; empty transportation vehicles; bridges (representing the capability to improve the transportation network) and a single, aggregated type of general supplies.

The ability to receive resources into the theater may be constrained by a user-designated port input capacity. A game-theoretic technique may be used to allocate port input capacity among some of the arriving resources. Delivery of resources to the forward areas may also be constrained by the capacities of the ground lines of communication and/or airlift aircraft. These aspects of the model are discussed in the section on "Logistics: Resource Flow and Transportation."

Allocation of Resources

After general supplies emerge from the transportation system they are allocated to the two regional depots for ground units and to the two regional air base depots in proportion to the current day's nominal supply requirements. Supplies from the ground depots are further allocated to units based on their requirements. If there are sufficient supplies in the regional depot, all the supported ground unit requirements will be met. If there is a shortage of supplies in the depot, the available supplies are allocated to combat units based on their current

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day's requirements. The supplies required by the ground forces in a region include the requirements of: the maneuver units on line in the sectors of the region; the reserve units and elements that may be used in the sectors of the region; the battalions in the pool of "fought-out" battalions that fought in the sectors of the region; the air defense artillery battalions in the sectors of the region; and the artillery tubes and helicopters used in support of the forces in the region. The amount of supplies required by the maneuver units is the sum of the requirements for each of the three types of battalions and is multiplied by two factors. These factors account for differences in terrain and in the postures (activities) of the units.

The amount of supplies that the air base depot allocates for use today is dependent on the level of depot supplies and the amount of supplies required by the air forces. If the amount in the depot is greater than the amount required, all requirements will be met. If the amount in the depot is less than required, all supplies in the depot will be allocated. Requirements per sortie are input by the user on the basis of aircraft and mission type. When supply shortages exist, the available supplies are allocated proportionately to each aircraft and mission type.

Replacement SAMs are allocated to SAM depots, which are not given a specific location in the model. Replacements of individual infantrymen, tanks, and APCs are allocated to combat units based upon the model user's choice of four possible replacement policy options: pure unit replacement policy; modified unit replacement policy; modified individual replacement policy; and pure individual replacement policy. These options are discussed in detail in the section on personnel replacements.

Additional aircraft arriving in the theater are given a destination by the model user and assigned directly to regions.

Effects of Resource Shortages

A shortage of general supplies in a region reduces the number of ground maneuver forces which may be committed to combat in sectors of the region. The fraction of units which are employed is equal to the fraction of required supplies which are available. Supply requirements of each unit are based on unit type, the terrain, and the posture, or activity, of the unit. For artillery units, a shortage of supplies causes a proportional reduction in the number of artillery rounds which may be fired.

The supply requirements of air forces are based upon the number of planned sorties, the type of aircraft, and the type of mission. Shortages of supplies cause a proportional reduction in the number of sorties which can be flown. The fractional reduction is equal across all types of aircraft and missions. Calculations regarding supply availability are made on a regional basis.

A shortage of SAMs for ADA units causes a proportional reduction in the number of SAMs which are fired. General supplies are not specifically considered for SAM units.

The numbers of infantrymen, tanks, APCs, helicopters, artillery pieces and tactical aircraft on hand are directly considered in the attrition calculations. Therefore, no modifications to basic calculations are necessary to reflect shortages of these resources.

a. Inputs by User

- On-line maneuver unit requirements for supplies by types of unit, posture and terrain.
- Supply requirements for maneuver units in reserve and in "fought-out" pools, by type.
- Choice of four possible policy options for allocation of infantry, APC and tank replacements.
- Initial stockpiles of supplies in regional ground and air depots, and in units.

- Supply requirements by aircraft and mission types, per sortie.
- Number of SAMs necessary in each ADA battalion for nominal operation.
- Supply requirements for field artillery, per tube, for nominal operations, per day.
- Supply requirements for each helicopter, per sortie.
- Ground unit TOE authorizations of personnel and equipment, by type and national participant.
- Initial personnel and equipment strengths of ground units, by type of unit.

b. Inputs Generated by the Model

- The amount of general supplies, in tons, emerging each day from the transportation network.
- The number of SAMs emerging each day from the transportation network.
- The daily numbers of replacement personnel, by national participant, and equipment items, by type, emerging from the network.
- Daily updated equipment and personnel strengths in ground units, by type, national participant, and status (on line in sectors, in reserve, etc.).
- The postures of ground forces in the sectors.
- The planned number of tactical aircraft and helicopter sorties, by type, by mission, daily.
- The planned number of artillery rounds to be fired, daily.
- The number of SAMs fired, daily.

c. Outputs

- Amount of supplies consumed daily, by element which consumes them.
- Amount of supplies on hand in regional ground and air depots.
- Fraction of ground forces which may be committed daily, considering supply constraints.
- Fraction of planned tactical air and helicopter sorties which may be flown, considering supply constraints, daily.

- Daily fraction of nominal number of SAMs and field artillery rounds which may be expended, considering supply shortages.
- Daily number of replacement items of equipment (and personnel) received by each unit, by unit type, location, and status.

d. Assumptions

- All consumable supplies (e.g., ammunition, POL, food) may be aggregated into a single class of general supplies for theater-level combat analysis.
- A shortage of general supplies causes a directly proportional reduction in the number of ground maneuver units which may be committed to combat, the number of tactical aircraft and helicopter sorties flown, and the number of field artillery rounds expended.
- The number of SAMs which may be fired is directly proportional to the fraction of nominally required SAMs on hand.
- Once general supplies have been received at regional depots, there is no time lag in delivering them to units.
- For units of a given type and status, allocations of replacement equipment are proportional to the number needed to attain TOE authorization. (Allocations among units of differing status are governed by input equipment and personnel replacement policy options.)

4. VECTOR

Supplies of the following types (27 types) can be represented in the model: ammunition for maneuver unit weapon systems, 9 types; land mines; field artillery ammunition; long and short range air defense ordnance, one type each; 10 types of ordnance for tactical aircraft, one type for helicopters; aviation POL; ground POL; one type of other supplies. Each type of supply can be stored at the local level, the sector level, and in the rear area. Ammunition and ordnance are assigned to individual Blue maneuver battalions (or Red regiments) and other using units in sectors, to sector stores, and to theater stores. Mines are assigned to individual maneuver battalions, sector

stores and theater stores. POL is assigned to individual battalions, sector air forces, sector stores, and theater stores.

Consumption of supplies is the result of combat activity and the passage of time. Except for expenditures of ammunition for maneuver unit weapons and expenditures of land mines, supply consumption for each consuming element is computed using input linear consumption rates. The rates may vary according to the type of activity engaged in by the consuming element. Consumption of the various types of supplies may be based on the total number of personnel and/or the numbers of consuming weapons, by type.

Specific consumption processes vary by type of supply. Aviation POL is consumed based on the input consumption rates times the numbers of sorties flown by each aircraft type, for each mission. Ground POL is computed based on numbers of battalion maneuver units, field artillery pieces and air defense weapons as well as the number of men in reserve, the number of personnel-kilometers of FEBA movement, and the total number of personnel per sector, per day. Consumption of aviation ordnance may be simulated for each aircraft-mission combination (5 aircraft types, 7 mission types). It is calculated by multiplying a user input of the ordnance expended by type for each aircraft-mission combination times the number of sorties of that type flown per day for each sector. Consumption of attack helicopter ordnance and the ammunition consumption of fixed ground weapons in returning fire on the helicopters is a function of the number of helicopters (up to 12) per flight. These quantities must be estimated by the user from the ordnance load of the helicopters and the dynamics of combat in such an engagement.

Consumption of ammunition for maneuver unit weapons is proportional to the firing activity represented in the firepower process models. That is, consumption by maneuver battalions at

the FEBA during an assault is computed at each range step in the differential models of combat. It is the expected number of rounds fired to achieve the expected attrition calculated in the model. For non-assault activities such as withdrawal, delay, inactivity, advance against delay, and pursuit, ammunition consumption is not explicitly modeled. Instead, average ammunition consumption of each of the nine ground type weapons for each of these types of activity is specified by the user. Field artillery ammunition expenditure is based on tactical decision rules specifying the total artillery rounds to be fired that day, in that sector, and the number which are allocated against front-line units (using the artillery fire process module). Artillery rounds to be fired which are not allocated against front-line units are used against reserves and rear area targets. Consumption of air defense ammunition is computed using the average quantity of ammunition fired by each randomly located weapon against each penetrating aircraft. The total ammunition expenditure is obtained by taking the product of the individual weapon consumption rate, the number of unsuppressed air defense weapons, and the average number of penetrating aircraft for each aircraft/mission combination. The daily consumption of other supplies is computed by multiplying input consumption rates per man, per day by the total number of personnel present. Land mines are consumed in proportion to the number of minefields which are employed. The number employed is determined by the tactical decision rules.

The logic for the allocation of resources among sectors and among elements within sectors is input by the user as tactical decision rules. Similarly, methods for determining the effects of supply shortages are specified as tactical decision rules, and are not included in the built-in model logic.

a. <u>Inputs by User</u>

- Consumption rate of supplies, by type of supplies and

by type of weapon systems. (Consumption of each type of ammunition is mathematically calculated at each range step for maneuver units.)

- Initial supply inventory, by type, at local unit level, sector, and theater.
- Tactical decision rules regarding allocation of supplies, by type.
- Tactical decision rules regarding the effects of supply shortages.

b. Inputs Generated by the Model

- The amount of supplies by type arriving daily at combat units, sector depots and theater stores.
- The current number of personnel on hand, by type and location.
- Equipment inventories, by type and location.
- The daily amount of FEBA movement for each battalion area.
- Expenditures of maneuver unit ammunition, by type and by battalion area class. These quantities are computed by the detailed firepower process models for attacks against hasty defenses. They are extracted from user-input lookup tables for other ground activities.
- Unit activities, for maneuver units.
- Degree and type of activity for non-maneuver elements, e.g., sortie rates and types of missions for tactical aircraft.
- Number of supplies destroyed, by type, in combat activities, e.g., air interdiction.
- Other existing model variables used in logistics decision processes, as specified by the tactical decision rules.

c. Outputs

- Supply totals remaining and totals used, by type of supply and by location.
- Effects on combat capabilities of supply shortages. These effects are determined in accordance with tactical decision rules programmed by the model user.

d. Assumptions

- Specific representation of the twenty-seven types of supply described above is adequate for theater-level combat analysis.
- For supplies other than maneuver unit ammunition, consumption can be determined by use of linear consumption rates. These rates may be multiplied by numbers of personnel and/or items of equipment or they may be multiplied by the number of activities, such as aircraft sorties, depending upon the type of supplies involved. Different rates may be applied, based on the type of activity which occurs.
- The assumptions pertaining to the attrition processes in an attack on a hasty defense apply to ammunition consumption for that activity.
- For a given type of maneuver unit, the amount of ammunition expended during any particular type of activity except an attack on a hasty defense is fixed by user input. It is unaffected by other aspects of the existing situation.
- After the decision is made to engage in an attack on a hasty defense, ammunition expenditure rates are unaffected by ammunition shortages. However, the availability of ammunition may be considered by means of tactical rules in making the decision to begin with. (It is theoretically possible to use tactical rules to modify firing rates and ammunition expenditure rates on the basis of ammunition availability, but the procedure is considered too cumbersome to have practical value.)
- Other assumptions will necessarily be employed by the user in designing the tactical decision rules which control resource allocation and the rules which determine the effects of supply shortages.

5. Discussion

Logistics activities are represented in the four models with varying degrees of aggregation. In all the models, the items of equipment (and personnel) which are specifically accounted for can be replaced on a daily basis from sources external to the theater of operations. Subsequent distribution of these items is, in general, based on need. The tactical

decision rules in VECTOR provide more flexibility in allocations than the other models, while in LULEJIAN the user can choose among four allocation policy options. CEM and IDAGAM each have a single built-in system for allocating replacement items. Both are based on need. The allocation of consumable supplies to using units is similarly based on need in three of the four models. In VECTOR, the logic for supply allocation is designed by the model user and programmed as tactical decision rules.

The models differ in the number of types of supply which are separately represented. VECTOR accounts for 27 types of supplies: 9 types of ammunition for maneuver unit weapons; 10 types of aircraft ordnance; helicopter ordnance; land mines; field artillery ammunition; long and short range air defense artillery ammunition (which may include missiles); ground POL; aviation POL; and a single additional "other supplies" category. In contrast, CEM, the model which accounts for the next largest number of types of supplies, represents only four: all POL, maneuver unit ammunition, artillery ammunition, and a single "all others" category. The IDAGAM and LULEJIAN models each represent one aggregated type of general supply and separately account for SAM consumption. In its unique modeling of the lines of communication, the LULEJIAN model uses and accounts for bridge and engineering supplies to represent road construction capabilities. The LULEJIAN model is also unique in its representation of vehicles (a single type) to transport supplies.

Given the differences in the resolution of the different types of supplies, most of the supply consumption process of the models are similar. Again, the clear exception is VECTOR, where each type of ammunition expended by opposing maneuver units during an attack on a hasty defense is calculated directly. Also, explicit counts are made of field artillery rounds expended and land mines employed. For the remainder of the VECTOR supplies, the consumption mechanisms are similar to those of

the other models.

In each of the models, consumption rates are input for various units, items of equipment, and/or personnel, based on the activity or the intensity of activity of the consuming element. The input rates are used as linear multipliers in the models. LULEJIAN is slightly more aggregated than the others, in that consumption rates are applied to units without regard to their actual daily equipment and personnel strengths. Unit consumption rates in the LULEJIAN model are modified according to force posture and type of terrain.

Each of the models, except VECTOR (discussed separately in the following paragraph), contains logic to assess the effects of supply shortages on the force capabilities. The means used in all three models are consistent with their overall structure. In CEM, shortages of each type of supply cause a degradation of total firepower values. Effects of shortages of more than one type of supply are multiplicative. Supply shortages in IDAGAM cause a reduction in the destruction of potential enemy weapons value, or alternatively, the number of potential enemy casualties, inflicted by each firing weapon. The degree of reduction for a given shortage is input by the user. In LULEJIAN, the number of maneuver units available for employment is reduced if supplies are below the required amount. This reduction of available units is proportional to the supply shortages. In both IDAGAM and LULEJIAN, shortages of supplies for aircraft cause a proportional reduction in the number of sorties which can be flown.

In the VECTOR model, all effects of supply shortages must be modeled by the user and input as tactical decision rules. It, therefore, has a good potential capability to assess those effects. Almost any internal model decision can take the supply status into consideration. Among the decisions which can be affected are those which select combat activities for maneuver

units. However, once an activity is taking place, its outcome cannot for practical purposes be made to reflect varying levels of supply.

VECTOR is considered better than the other models in representing supply consumption. More types of supply are explicitly represented, and ammunition expenditure processes are integrated into the attrition processes. There is little difference among the consumption processes in the other models, except for specific features, e.g., LOC construction in LULEJIAN.

Apart from VECTOR, the models are considered equally capable of representing the effects of supply shortages. The processes employed are consistent in each case with the overall structures of the models. VECTOR cannot be directly compared with the others since it contains no built-in logic to assess the effects of shortages. The amount of detailed data generated in the model gives it a good potential capability if users are willing to develop the appropriate logic as part of the tactical decision rule process.

M. LOGISTICS: RESOURCE FLOW AND TRANSPORTATION

1. CEM

Supplies and replacement weapons are received into the theater according to a schedule which is input by the user. The scheduled quantities are intended to represent receipts from both theater stockages and sources outside the theater. Three major categories of consumable supplies can arrive in the theater: POL, ammunition, and "all other" types. Each major weapon system, by type, can arrive. Immediately after resources are received, they are sent to depots somewhere near the front-line units. Repaired weapons which became available are sent along with them. The transportation system is implicitly represented by delays which are incurred in the movement of resources to the front. The amount of the delay for each resource being transported is a function of the tactical air "environment." When the enemy has air superiority, the results of air interdiction are implicitly represented as longer transportation times. No supplies are destroyed by interdiction in route, or for that matter at any other time or location. The time delays for friendly and unfriendly air environments are input by the user, but in no case can resources arrive in forward depots during the same theater cycle that they arrive in theater.

Supplies are allocated to using organizations from depots at the front according to need. Delivery is made during the next division cycle after the need is generated. No transportation delays are simulated for these deliveries.

The representations of depots and transportation are conceptual only. Only aggregated simulations of their effects are explicit within the model.

a. Inputs by the User

- Schedule of arrivals of consumable supplies and major weapons systems into the theater, by type, by theater cycle.
- The amount of time required to move supplies from the theater point of entry to the forward supply depots, by type of supply, for friendly and unfriendly air environments.

b. Inputs Generated by the Model

- Status of the tactical air environment, friendly or unfriendly.
- Number of weapons, by type, which have been repaired and sent to forward depots along with new replacement weapons.

c. Outputs

- The quantity of supplies and replacement weapons received at forward depots during each theater cycle.
- Updated total quantity of supplies and replacement weapons on hand at forward depots.

d. Assumptions

- Allocations of supplies from theater to geographic areas are perfect. Supplies are always sent to the proper forward depots for subsequent allocations to combat units on the basis of need. The needed supplies are assumed to be in depots close enough to the units having the need so that delays in delivery are avoided.
- Air interdiction affects only the time required to transport supplies. No supplies are destroyed, either in transit or in depots.
- The capability to transport supplies is affected only by the status of the air environment. Changes in other aspects of the ongoing combat situation have no effect.

2. IDAGAM

Consumable supplies of a single notional type enter the theater according to a schedule which is input by the model user. They are distributed by means of a supply system which stores and accounts for them at three echelons: COMMZ, regions, and sectors. The supplies intended for use by organizations physically located in the COMMZ and in regions are accounted for in depots separate from the depots which provide supplies to lower echelons. Supplies are allocated from COMMZ to region to sectors on the basis of need. They are also allocated to organizations within the COMMZ and regions on the same basis. Supplies in the combat sectors are immediately available to the divisions in those sectors without further explicit allocation.

Transportation of supplies is represented implicitly. No lines of communications nor transportation resources are portrayed in the model. Movements of available allocated supplies from COMMZ to regions take place without restrictions, and are not subject to air interdiction. Each such transfer of supplies is completed during a single model time period, e.g., one day. Supply transfers from regions to sectors are also accomplished in one day, but here the movement is subject to air interdiction. Attack by aircraft can cause destruction of supplies, or can block their movement. Blocked supplies are returned to region depots. (See section G of this appendix, "Air Interdiction," for details on how the quantities of affected supplies are calculated.) Supplies which arrive in sectors are assumed to be immediately available to the divisions there, and no movement of supplies is represented.

Supplies may be transferred back and forth between the supply depot which supports the theater. Similar transfers may be made between the two analogous storage locations in each region. Supplies are not subject to air interdiction while being transferred in this way. No supplies can be automatically

moved rearward, that is, from sectors to regions, or from regions to the COMMZ. However, all resources, including supplies can be administratively moved as desired by means of specific user inputs.

Supplies stored in the COMMZ are not subject to attacks of any kind. These stored in regions are subject to destruction by aircraft, and those in sectors can be destroyed by both aircraft and ground weapons.

(Other resources which enter the theater, i.e. replacement weapons and personnel, are not a part of the supply system which is described in this section. For a discussion of the IDAGAM treatment of the flow of these resources in the theater, see section P of this appendix, "Personnel Replacements.")

a. Inputs by the User

- Schedule of arrival of supplies into the theater. A single notional type of consumable supplies is represented.
- Desired supply stockage levels in sectors and regions.

b. Inputs Generated by the Model

- Supply consumption by each organization in the theater, by location.
- Amounts of supplies destroyed by ground and air attack in each sector.
- Amounts of supplies destroyed by air attack in sectors and regions, and in route from regions to sectors.
- The amount of supplies blocked by air interdiction and consequently not transported from region depots to sectors. (Blocked supplies are returned to the region depot from which they were shipped.)

c. Outputs

- The amount of supplies needed at each location to meet desired stockage levels (the demand).

- The amounts of supplies shipped from COMMZ to regions, and from regions to sectors.
- The amounts of supplies shipped between the two locations accounted for in the COMMZ and between the two analogous locations in each region. (See descriptive paragraph above for an explanation of the two locations.)
- Updated supply inventories by location.

d. Assumptions

- Supplies are invulnerable to attack while in the COMMZ or in route from the COMMZ to regions.
- Supplies in regions and in route from regions to sectors are vulnerable to attack by aircraft only.
- Supplies located in combat sectors are vulnerable to attack by aircraft and ground weapons.
- The effect of air interdiction of lines of communications is to block the delivery of some portion of the supplies which are being transported.
- In addition to the destruction of supplies, air interdiction can cause the movement of some portion of them to be blocked, forcing their return to the point of orgin.
- Supplies can be transported from the COMMZ to regions in a single model time period, typically one day.

3. LULEJIAN

The theater logistics system is represented by a point of entry into the theater (the port), forward supply depots in each region, and a ground transportation system from the port to the forward areas. The following resources can be introduced into the theater through the port: infantry battalions, mechanized infantry battalions and tank battalions, by national participant; ADA battalions; replacement infantry personnel, by national participant; replacement tanks and APCs, by type; replacement SAMs; general consumable supplies; empty transportation vehicles; and bridge sections as a surrogate for materials to improve the ground lines of communications (LOC). The port

has a maximum daily capacity, in tons, to accept resources. Priority for use of this capacity is given to replacement units, equipment, and personnel; their arrivals are scheduled by the model user. Remaining capacity of the port to accept resources is devoted to general supplies, transportation vehicles, and bridges. The fraction of the remaining capacity which is devoted to each of these latter three resources can be determined by the "optimization" algorithm, or can be fixed by user input. In either case, the absolute amounts of the three non-priority resources are dependent on the port capacity remaining after acceptance of priority resources, and on the fraction of that capacity allocated to each of the three. Sufficient quantities of the three resources are assumed to be available for acceptance by the port so that all capacity is utilized.

As mentioned above, the fraction of the remaining port capacity to be allocated to each of the three non-priority resources can be determined by the "optimization" algorithm. The algorithm uses an approximate solution technique for a two-sided, multi-stage, zero-sum game. Each side allocates port acceptance capacity so as to maximize the results of the game to its own advantage. That is, each side attempts to obtain the maximum amount of FEBA movement in its own direction of forward progress. Simultaneous decisions are not made by both sides. At each decision point, one side must decide on an allocation, and the other side must then respond with its own allocation decision. Decisions are in the form of a selection from a set of discreet "strategies" input by the user. Each strategy is a fractional allocation of available capacity to each of the three non-priority resources. For example a single strategy might be expressed as: "Allocate 50 percent of available port capacity to general supplies, 30 percent to transportation vehicles, and 20 percent to bridges." The algorithm does not solve for a mixed-strategy solution and does not in fact

obtain a rigorous solution to either a maxmin or minmax problem. Further, there is no capability to determine bounds between which the correct solution must fall. The algorithm does provide a method of analyzing the effects which variations in capacity allocations have upon the outcome of the combat simulation. It automatically generates sequential allocations which are relatively good for the side making them even if they are not necessarily the correct solutions. (To the authors' knowledge, the state of the art does not allow for rigorously correct solutions to problems of this nature, unless the basic combat simulation is purposely made very simple.) If operation of the algorithm is not desired, all the allocation strategies for each decision point may be fixed in advance by the model user.

Resources which have entered the port are eligible for shipment to forward areas. All resources in the port except supplies are assumed to be needed or "demanded," by forward elements. Demands for supplies are computed on the basis of quantities authorized and on hand in the forward areas. If the quantity demanded is the same as or greater than the quantity available in the port, then all available supplies are designated for shipment. If the quantity in the port exceeds the demand, the following equation is used to determine the quantity designated for forward shipment:

Let Sp = quantity of supplies available in the port
Sd = quantity demanded by forward elements
Ss = quantity designated for shipment

$$Ss = Sd + 0.5\ Sd\ (1 - e^{-\frac{(Sp - Sd)}{0.5Sd}})$$

This equation limits the quantity of supplies designated for shipment to no more than 1.5 times the quantity demanded.

Since all resources in the port except supplies are assumed to be needed by forward elements, all are designated for shipment.

Some means of transportation is required for all resources once they have been designated for shipment. All types of replacement battalions are assumed to possess adequate organic transportation capability for movement to forward areas. The other resources must be moved either by airlift aircraft or by ground transportation vehicles. Airlift capacity is first allocated to individual infantry personnel replacements; if any capacity is left over, it is used for general supplies. No other resources can be transported forward by aircraft.

All bridges and replacement equipment are moved forward by ground transportation vehicle (a single notional type of truck). Replacement personnel and supplies not transported by airlift are also carried by trucks. Less than perfect efficiency in loading vehicles is assumed; the following equation is used to compute the number of vehicles which are loaded daily.

$$V_{in} = Vp \left(1 - e^{\frac{-r_{nt}}{tv\ Vp}}\right)$$

Where

r_{nt} = total tonnage at port to be placed on transport vehicles.

t_v = capacity of each vehicle, in tons.

V_p = number of empty vehicles in the port.

V_{in} = number of vehicles which are loaded and enter the transportation network.

If there is not enough total vehicle capacity to carry all the resources which have been designated for shipment, some of each type of resource will remain in the port. The same fraction of the demand for each resource is shipped; for example, if only 60 percent of needed transportation capacity is available, then 60 percent of the amount of each resource demanded will be shipped. The entire quantity of all resources in the port except consumable supplies is assumed to be "demanded."

The time necessary for vehicles to move from the port to forward areas through the supply network depends on the capacity of the network and the distance which must be traveled. The number of vehicles emerging from the network each day is computed with the following equations:

$$V_{out} = C_n \left(1 - e^{\frac{-V_n}{t_{Cn}}}\right)$$

Where

V_{out} = the number of vehicles that emerge from the network today.

C_n = the network capacity (vehicles/day).

V_n = total number of vehicles in the network today.

t = the average miminum time required for vehicles to flow through the network.

t is computed using the following:

$$t = \frac{D_{p1} + D_{p2}}{2\ S_v}$$

where

D_{p1} = the average distance from the Region 1 FEBA to the port.

D_{p2} = the average distance from the Region 2 FEBA to the port.

S_v = the speed of the vehicles.

When the network capacity is small in relation to the number of vehicles in the network, the vehicle through-put is limited to that capacity (a bottleneck). When the capacity is large in relation to the number of vehicles, the number emerging from the network is the total number in the network divided by the transit time required. The number of emerging vehicles carrying a given resource is proportional to the total number of vehicles in the network which are carrying that resource. For example, if half of all the vehicles in the network today are carrying general supplies, half of today's emerging vehicles are assumed to be carrying general supplies.

The capacity of the network is influenced by the number of bridges available, as follows:

$$C_n = B_{em} \cdot (\frac{B_{vc})}{B_{prc}}$$

where C_n = increase in network capacity due to added river crossings.

B_{em} = number of bridge sections emerging from the network.

B_{vc} = capacity increase (vehicles/day) per river crossing constructed.

B_{prc} = bridge sections required per river crossing.

Resources and transportation vehicles are susceptible to air interdiction after they have left the port. Bridges may also be destroyed, reducing the network capacity, and possibly causing delays in movement. (See section G, this appendix, "Air Interdiction.")

In addition to bridge sections, an input quantity of general supplies is consumed in the construction of each river crossing. Supplies required for this purpose are a part of the total demand placed upon the port.

After supplies for the forward area have emerged from the transportation network, they are placed in region depots. There is a supply depot for ground forces and a separate supply depot for the air base in each region. Supplies emerging from the network are allocated among these depots in proportion to demand. Once supplies are in the depots, they are assumed to be immediately available to the users. No further transportation or delays are simulated. Similarly, SAMs emerging from the network are placed in SAM depots and are allocated out of them based on demand. Movement of SAMs from forward depots to firing units is not simulated.

Replacement personnel and equipment emerging from the transportation network are allocated to units in accordance with user-selected options. This is discussed in sections L,

"Logistics: Structure, Consumption and Availability," and P, "Personnel Replacements," of this appendix.

Tactical aircraft, airlift aircraft, and helicopters can be scheduled into the theater by the model user. They are assumed to go directly to their appropriate operating areas without reference to the port or other elements of the logistics system.

a. Inputs by the User

- Arrival schedule for the following resources, which have priority for use of port capacity:
  - (1) Infantry, mechanized infantry, and tank battalions, by national participant.
  - (2) ADA battalions.
  - (3) Replacement infantry personnel, by national participant.
  - (4) Replacement tanks and APCs, by type.
  - (5) Replacement SAMs.
- Port input capacity, in tons per day.
- Unit weights, in tons, for all incoming resources except general supplies.
- Inventory of all resources in the theater at the beginning of the combat, and their locations.
- Number of airlift aircraft initially in theater, and schedule for future arrivals.
- Carrying capacity of the single notional type of airlift aircraft.
- Number of transportation vehicles (a single notional type) initially on hand, and their locations.
- Carrying capacity of the transportation vehicle.
- Average speed of the transportation vehicle, in kilometers per day.
- Initial capacity of the ground transportation network, in vehicles per day.
- Initial FEBA locations in each sector, in relation to the location of the ports for each side.
- Initial number of river crossings in the network.

- The increase in ground network capacity (vehicles per day) derived from the construction of each river crossing.
- Number of bridge sections needed to construct a single river crossing.
- The quantity of general supplies needed for construction of a single river crossing.
- The quantity of general supplies necessary for maintenance of a unit length (km) of the ground transportation network for one day.
- Selection of the method by which the capacity of the port to accept incoming resources is allocated among general supplies, bridge sections, and transportation vehicles. The allocations may be determined by the "optimization" algorithm, or they may be fixed in advance by the model user.
- A set of allocation strategies for port input capacity. Each strategy enumerates the fraction of available capacity to be allocated to general supplies, bridge sections, and transportation vehicles.
- The number and lengths of the periods during which no changes in port allocations will be made. Decision points occur at the beginning of each period.
- Initial trial allocation strategies for each side for each decision point. These are used as a starting point by the optimization algorithm.
- Selection of the type of approximate optimization to be performed, if fixed strategies are not selected. The type of optimization can be selected for each move individually. The choices are:

  (1) Minmax

  (2) Maxmin

  (3) Min (one side holds fixed strategies)

  (4) Max (the other side holds fixed strategies)

b. Inputs Generated by the Model

- Amounts of the general supplies needed (demanded) by forward area depots.
- Amounts of resources other than general supplies which are needed by combat elements in the forward areas.
- Updated FEBA positions in each sector.

- Quantity of resources, ty type, destroyed by air interdiction of the ground transportation network and forward depots. Resources in the port and those being moved by airlift aircraft are not subject to attack.
- Number of river crossings destroyed by air interdiction.

c. Outputs

- Quantities of general supplies, bridge sections, and transportation vehicles arriving into the theater port each day.
- The amount of port capacity available for the acceptance of incoming general supplies, bridge sections, and transportation vehicles each day, and the fraction of that capacity which is allocated to each of the three resources.
- The quantity of each type of resource shipped forward from the port each day by means of airlift aircraft, organic vehicles, and the notional ground transportation vehicles.
- The quantities of resources by type, emerging from the ground transportation network each day. The number of emerging transportation vehicles which are carrying these resources is also given.
- The numbers of ground transportation vehicles in the theater, daily, by status:

  (1) Ready for loading at the port.

  (2) Moving resources forward from the port.

  (3) Returning empty back through the supply network to the port.
- The number of river crossings constructed each day, and an updated total number in the transportation network.
- The quantities of general supplies which are consumed in the transportation network, daily.

d. Assumptions

- There is an inherent maximum quantity of resources, in terms of tonnage, which can be accepted into the theater each day (represented as the maximum acceptance capacity of the notional port). There is no comparable inherent limitation on the storage capacity of the port, nor on the daily quantity of resources which can be

shipped forward from it. The quantity which can be shipped forward is constrained, but only by the theater transportation system.

- In the utilization of the constrained capacity to accept resources into the theater, all replacement units, personnel and equipment are accommodated before any capacity is allocated to general supplies, bridge sections, or transportation vehicles.
- The only limitation on the availability of general supplies, bridge sections, and/or transportation vehicles for shipment into the theater is the capacity of the notional port to accept them.
- The levels of aggregation of resources and the logistics network as previously described in this section are adequate for theater-level combat analysis.
- The exponential equations, described above, which are used to calculate the number of vehicles loaded at the port and the number which emerge from the network are adequate, average representations of the processes involved.
- The use of game theoretic techniques is appropriate for making unbiased allocations of limited port capacity to general supplies, bridge sections (LOC construction material) and transportation vehicles. The algorithm used is assumed adequate for finding "good" allocations, even though the relationship of the solution it generates to the correct solution cannot be verified. (This assumption is applicable only if the user employs the optimization algorithm; it is not applicable if fixed, predetermined allocations are used).
- Although replacement crews are an integral component of replacement tanks and APCs, these vehicles must be carried forward from the port by transportation vehicles.
- The ground LOC consists of a sufficient number of parallel roads so that air interdiction can reduce its capacity but not shut off movement entirely, even temporarily. That is, no critical "choke-points" exist. Destruction or construction of a river crossing changes the nominal capacity of the transportation network by a fixed, input amount.

4. VECTOR

Any resource which is represented in the model can be scheduled to enter the theater during the conduct of the campaign. This includes all types of maneuver units, personnel, weapons, ammunition, POL, land mines, aircraft, aircraft ordnance, aircraft shelters, and "other" supplies. Resources may arrive at specifically designated sectors or they may arrive at the theater level. All resource allocations must be made by tactical decision rules devised and programmed by the model user, e.g., from theater level to sectors, or from sectors to maneuver units.

No transportation system or lines of communications are represented in the model. Most resources may be located at theater level, sector level, and using-unit level, but the process of movement between these levels is not modeled. Some effects of movement, such as delays, may be programmed into the tactical decision rules. The degree to which this is done is left to the discretion of the model user. Allocation and use of resources is of course reflected in updated inventories for each storage location or using unit.

a. Inputs by the User

- Schedule of resource arrivals. Resources of all types may arrive on any or all days that combat is simulated. (And, as a technique for deploying resources, some may arrive and be allocated on the "day" before combat begins.)
- Quantities of resources authorized or required, by location or unit.
- Tactical decision rules to allocate resources.
- Tactical decision rules to simulate in some degree the transportation of resources.

b. Inputs Generated by the Model

- Quantities of resources consumed or destroyed, by location or unit, daily.

- Updated quantities of resources on hand at each location or unit.
- Any other state variables which the tactical decision rules have been programmed to use.

c. Outputs

- Quantity of resources, by type, arriving at each location or unit, daily.

d. Assumptions

- Resources can be stored at three levels in the theater: theater stores, sector stores, and at the using organization.
- Resources can be sent directly to a designated sector from outside the theater, or they can be sent to the theater as a whole for subsequent allocation.

(In his formulation of tactical decision rules, the model user will probably make numerous additional assumptions.)

5. DISCUSSION

All the models except VECTOR represent in some way the movement of resources to the forward areas from the point of entry into the theater. (The allocation of resources after they arrive at the forward areas, and the effects of these resources, particularly supplies, on the combat units are discussed in section L, this appendix.) The representation of the point of entry (the port) and the transportation system to the front is far more detailed in LULEJIAN than in the other models. Capacities and capabilities are expressly represented, and computations are made using assumptions and equations which are reasonable, given the level of aggregation. Transportation in the other models is essentially a simple transfer of resources from storage locations in the rear to depots further forward. Movement time is simulated in CEM by delay times input by the user. In IDAGAM, each forward movement, e.g., from COMMZ to

regions, requires a single model time period (a single day). VECTOR has no built-in transportation system, but delays can be programmed in the tactical decision rules.

In general, each model portrays a rear area where resources are invulnerable to attack. As resources are moved to more forward areas, they first become vulnerable to air attack, and then to other types of attack as well. In CEM, resources are delayed by air interdiction, but are not destroyed. Since VECTOR does not represent movement as such, resources in transit are not attacked.

All of the models accept resupply of the non-consumable resources which they represent. All also accept consumable supplies, but at differing levels of aggregation. VECTOR is the most disaggregated, while IDAGAM and LULEJIAN aggregate consumables into a single category of "general supplies."

LULEJIAN is clearly more thorough than the other models in its representation of the transportation system, but it is highly aggregated. Since the other models do not treat internally the possibility of a finite port capacity, the function of the LULEJIAN allocation algorithm is unique. Although the validity of the algorithm cannot be proven, the algorithm cannot be considered a weakness of LULEJIAN in comparison with the other models. It can be overridden and the port capacity can be made large enough so that no practical constraints exist. Care should be taken with the user input, however, since there are assumed to be enough general supplies, bridge sections, and/or transportation vehicles available for entry to the port to utilize all the capacity remaining after higher priority items have entered.

All the models except VECTOR assume that allocation and distribution of resources from theater level down to lower echelons is perfect, based on need. The user must design and program the allocation scheme for VECTOR.

None of the models except LULEJIAN is considered suitable for study of questions pertaining to theater logistics. In CEM, IDAGAM, and VECTOR, the value of this functional area is in its acceptance of units, supplies, and replacement resources into the theater, thereby allowing some assessment of their effects on the course of the campaign. LULEJIAN can be used to examine theater logistics, but its usefulness for this purpose is limited by its high level of aggregation.

N. LOGISTICS: MAINTENANCE AND REPAIR

1. CEM

Theater level depot maintenance support for all tanks, APCs, and helicopters which are assigned to combat units is provided. This represents all maintenance and repair of combat damage above division level. It requires that the user provide inputs for the proportion repaired, repair capacity, and repair time for each generic weapon system (e.g., all 12 tank types have the same values for each of the three inputs). Excessive requirements for maintenance and repair result in a queue and its attendant delays. Repaired weapons are assigned to the appropriate theater distribution pool on a time-phased basis which reflects the capacity of the depot maintenance facilities.

a. Inputs by User

- Proportion of total numbers of a given generic weapon system (e.g., all tank types) which can be repaired.
- Repair capacity for each weapon system.
- Repair time for each weapon system.

b. Inputs Generated by the Model

- Combat unit weapon systems losses by type system (tank, APC, helicopter) by theater cycle.

c. Outputs

- Weapon systems (tank, APC, helicopter) in repair, by theater cycle.
- Weapon systems, by type, as gains to appropriate theater distribution pools.

d. Assumptions

- User has knowledge of the proportion of each damaged weapon system which can be repaired during a battle.

- User has knowledge of theater level maintenance repair capacity for each weapon system type, and the time expected to complete repairs.

2. IDAGAM

Ground combat weapons engaged in battle each day may become damaged in the process. Some may be repairable. However, aircraft damaged in combat cannot be repaired.

a. Inputs by User

- Percentage of ground combat weapons, by type, damaged each day which are repairable.

b. Inputs Generated by the Model

- Number of ground weapons, by type, engaged in battle that become damaged, per day.

c. Outputs

- Number of damaged ground weapons, by type, which have been repaired and are added to the weapon replacement pool in the communications zone.

d. Assumptions

- A constant daily percentage of all damaged ground weapons, by type, can be repaired regardless of battle intensity, or peculiarities in individual sectors.
- Supplies and spare parts of all types needed, by weapon type, are available to repair the percentage of combat disabled weapons per day and return them to a weapon replacement pool.
- The repair function causes no supplies to be withdrawn from any supply pools, and there is no consequent reduction in the amount of consumable supplies available.

3. LULEJIAN

The maintenance and repair function for ground systems and aircraft are not considered explicitly in the model.

4. VECTOR

The effects of maintenance and repair of ground and air weapon systems are not simulated in the model.

5. DISCUSSION

The maintenance and repair function is represented in only two of the four models, and in those it is simulated in a very cursory manner. CEM contains a theater-level depot maintenance support function to repair tanks, APCs, and helicopters. However, the user must input for each type of weapon system such parameters as the expected fraction of the total number damaged which can be repaired, depot repair capacity, and length of time to repair each type of weapon system. Excessive requirements and/or limited depot maintenance can create queues, and delays in the return of weapons to combat. IDAGAM also permits limited repair and maintenance, However, only ground weapons are repairable. Aircraft damaged in combat are not recycled, and again, the user inputs the percentage of each type ground combat weapon which can be repaired per day. No queues or delays are created within the model. Neither the LULEJIAN nor the VECTOR models explicitly considers the maintenance and repair functions.

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O. CONSTRUCTION

1. CEM

The model simulates in an aggregated sense the construction of defensive positions (prepared defenses or barriers). There is a presumption made within the model that, when the FEBA within any subsector is stationary or moving very slowly, both sides will construct defensive positions. Either a prepared defense or barrier will be constructed, depending on the force capability specified by the user. A time-average rate of FEBA movement is maintained for every minisector along the FEBA. When the average movement rate over the minisectors in a given subsector is below an input threshold value, a defensive position is constructed. It is possible to differentiate between construction capabilities of the various Blue units (divisions) by inputting different threshold rates for the units. All Red units are assumed to have the same construction capability, and a single threshold value is input for that side. Requirements for construction materials are not considered in the model.

The presence of defensive positions causes modifications of firepower scores and modifications of input FEBA movement rates. The modifications are to the advantage of the defender.

a. Inputs by the User

- Threshold FEBA movement rates, below which construction of defensive positions may occur. For Blue, these are input by unit; a single threshold value applicable to all units is input for Red.
- The time average weighting coefficient, by side, used to compute average FEBA movement over time in each minisector.

b. Inputs Generated by the Model

- Actual FEBA movement for each time period (division cycle) for each minisector.

- The identification of each Blue unit at each subsector, for determination of construction capability.

c. Outputs

- The location of each barrier and prepared defensive position, for each division cycle.

d. Assumptions

- The ability and decision of particular units to construct defensive positions are based solely on the time available to complete the construction.
- The availability of construction materials for particular Blue units and for all Red units is the same each time a defensive position is constructed throughout a given conflict, i.e., during a given model run.
- All Red units have the same capability to construct defensive positions.

2. IDAGAM

No construction activities are represented in the model. Prepared defensive positions may be used, but the locations are input and do not depend on the course of the battle.

3. LULEJIAN

Construction of lines of communication (LOC) is modeled in an aggregated manner. The ground LOC is represented as a single "pipeline" from the point of entry into the theater (the port) to the supply depots which support combat elements. Construction effort increases the through-put capacity of the LOC. All construction is represented in terms of bridges. The amount of construction is determined by the number of bridge sections available and is not constrained by the capabilities of the forces to perform the construction. The degree of utilization of the port through-put capacity for bridge sections may be determined by the LULEJIAN "optimization" algorithm. Bridge

sections, general supplies, and transport vehicles compete for the limited port capacity. Bridges can be destroyed by enemy air interdiction, causing a reduction in the capacity of the LOC unless the bridges are replaced. General supplies are also consumed in the construction of bridges. These are computed on the basis of the estimated man-days necessary to accomplish the construction. The construction effort, however, is constrained by the availability of neither general supplies nor man-days of effort.

a. Inputs by the User

- Initial number of bridges in place in the LOC.
- Number of bridge sections available to each side for input to its theater port, by day.
- Average number of bridge sections necessary to construct a bridge.

b. Inputs Generated by the Model

- The daily number of bridge sections leaving the port and becoming available for LOC construction.
- The daily number of bridges destroyed by interdiction aircraft.

c. Outputs

- The number of bridges in place, by day. This is used in determining LOC through-put capacity.

d. Assumptions

- Since they are not explicitly considered, terrain variations do not affect construction requirements or LOC capacity.
- All LOC improvements or damage can be represented in terms of numbers of bridges.
- The ability to construct bridges depends only on the availability of material, and not on the construction capabilities of the forces involved.

4. VECTOR

Construction activities are not represented in the model. Any desired considerations of the average effects of construction must be reflected in such input values as the FEBA movement rates corresponding to various force activities.

5. DISCUSSION

Two of the models explicitly treat some aspect of construction, but in a highly aggregated manner. CEM allows for construction of barriers and prepared defenses, providing that the rate of FEBA movement is sufficiently small. If there is adequate time available, construction will take place with no consideration of the availability of construction materials. When CEM defensive positions are in place, the FEBA movement rates and firepower scores are modified in favor of the defender.

The LULEJIAN model represents construction undertaken to improve the logistics ground transportation network. In contrast to CEM, the ability to perform construction depends entirely upon the availability of construction materials, represented by bridges. It does not depend on the capability of the forces to do the work. The effect of bridge construction is to increase the capacity of the logistics network; destruction of bridges by interdiction aircraft decreases the capacity.

IDAGAM and VECTOR do not explicitly represent construction. Some implicit representation of the average effects of construction or the lack of it may be reflected in other input values, e.g., FEBA movement rates under specified conditions.

None of the models is adequate for analyzing detailed construction activities and capabilities or for analyzing the effects of construction on the outcome of theater combat.

P. PERSONNEL REPLACEMENTS

1. CEM

Personnel are made available during each theater cycle from theater ports and theater hospitals to personnel distribution pools, with appropriate time delays for transportation and enemy air interdiction. From the theater pools the personnel are transported to the brigades (Blue) and divisions (Red) during the ensuing division cycles on the basis of need.

Each combat unit has an authorized personnel strength, equipment list, and initial load, and also has a current status of these resources as reported in its status file. The personnel replacements in the theater pools are distributed to the units as a function of unit need to replace personnel losses during each division cycle. If replacement personnel in theater distribution pools exceed requirements of the combat units, the excess personnel remain in the theater pools for the next division cycle. If the total number of available replacements is less than that required, then allocations are based on need. For example, if one unit requires twice as many replacements as another unit to attain full strength, it will be given twice as many from the number available. Of course, since a shortage exists, no unit will be brought to full strength.

The number and availability of personnel replacements is based on theater policy input to the model. Such inputs as TOE of each unit, the numbers of replacement personnel sent to theater ports, and delays in transport from ports to theater pools affect the number of replacements. At the beginning of each theater cycle, available personnel replacements are apportioned equally to the number of division cycles within the theater cycle, to become available to the units in need during each division period. New personnel replacements received by units are not immediately available for combat, but must be

assimilated into the unit over a period of time, (see section R of this appendix, "Ineffective New Troops").

For Red division personnel replacement, this procedure may be altered in order to play a Red doctrine of echelonment and depletion of on-line divisions while previously exhausted divisions are being rebuilt. This permits Red units on line to be decimated while receiving no personnel replacements. Replacements are allocated instead to previously decimated divisions which are being held in rear-area pools to be rebuilt. At the beginning of the corps cycle, the state of each on-line and reserve Red division is compared against a threshold value, which has one value if the corps mission is to attack and another value if its mission is to defend or delay. If the division state is below this threshold and there are currently more than two divisions belonging to the parent Red Army (CEM corps), the decimated division is transferred from the front to a decimation pool, and the frontage of an adjacent on-line division is expanded to occupy the gap. The decimated division is tagged for return to the same parent army after rebuilding and after a minimum duration in the decimation pool. The division is considered rebuilt with replacement personnel when its state exceeds a given threshold and the minimum time has elapsed. It is then transferred to the reinforcing pool for the appropriate army to be returned to the front in the next army cycle in which reinforcements are required.

a. <u>Inputs by User</u>

- The numbers of personnel replacements made available to each side during each theater cycle, including the initial cycle. These may vary from cycle to cycle.
- Designation of whether on-line Red divisions will be provided with replacements or be allowed to become decimated and subsequently rebuilt in the rear.
- The authorized (TOE) number of combat personnel for each type of unit.

- The initial numbers of personnel assigned to each unit.
- The amount of time required for replacement personnel to move from their point of entry into the theater (port) to the theater distribution pool.
- Threshold state values to denote decimation of Red divisions. With certain restrictions, if the state of a Red division falls below the threshold value, the division is considered decimated and is transferred to the rear. The threshold may be different when the parent corps is attacking than when it is defending or delaying.

b. Inputs Generated by the Model

- Current personnel status of combat units.

c. Outputs

- The numbers of replacement personnel available to be allocated during each division cycle to each combat unit on each side.
- The fraction of authorized personnel present in each combat unit on each side, at the start of each division cycle.
- The number and status of Red divisions, by type, being rebuilt in the decimated division pool, at the start of each division cycle.

d. Assumptions

- Personnel replacements are sent to individual combat units from theater pools based on the fraction of authorized personnel on hand per division cycle, i.e., replacements are made on the basis of need.
- At the beginning of each theater cycle, the available personnel replacements are apportioned equally to the division cycles encompassed by the theater cycle. They become available to user units during each division period.
- Personnel replacements will not be made so as to cause units to have more than TOE authorized strength.
- Personnel replacements sent to the personnel pool are not immediately available for assignment, but must be assimilated into the theater over a period of time.

- Red on-line divisions can be decimated without personnel replacements being made.
- Decimated Red divisions can be rebuilt with personnel replacements from theater personnel distribution pools.
- Red on-line divisions retire to decimation pools based on an input threshold value of the level of decimation.
- Replacements for combat units are not distinguishable according to skills, training or country of origin. These distinctions are not accounted for in the model.
- Shortages and replacements of non-combat personnel have no direct influence on the outcomes of theater combat. Such personnel are not represented in the model.
- For replacement personnel, transportation delays are incurred only for movement from theater ports to the theater distribution pools.

2. IDAGAM

When personnel and weapon replacements arrive in the theater, they are sent to theater replacement pools for subsequent allocation to divisions. In making the allocations, the model relates personnel replacements with weapon replacements. The two are related in that personnel replacements sent to a division without weapons provide no increased effectiveness to the unit. Similarly, replacement weapons do not contribute to the effectiveness of units which do not have sufficient personnel to man them.

A trial number of personnel replacements is first calculated. It is the minimum of the following three quantities: The number of people in the replacement pool, the number of people needed by all divisions in all sectors and all regions, and the number of people currently in the divisions times an input "pipeline" factor. (The "pipeline" factor represents an inability of units to absorb large numbers of replacements in relation to the number of personnel currently assigned to the units.) The trial number of personnel replacements is then prorated to the divisions according to need.

A "weapon replacement rate" is next calculated by type weapon, by division. It is the number of weapons needed by each division divided by the number of personnel replacements needed by the division.

A trial number of replacement weapons which are required, by type, by division, is computed. It is the minimum value of (1) the weapon replacement rate times the trial number of personnel replacements and (2) the number of weapons of a given type needed by the division.

The actual number of replacement weapons, by type, sent to each division is obtained by comparing the sum over all divisions of the trial number of replacement weapons needed with the number of weapons, by type, in the weapon replacement pool. If the weapon replacement pool inventory of weapons is less than the sum of the trial number of division weapon replacements, then the trial number of replacement weapons of that type is reduced proportionally for each division until the sum equals the number in the pool.

If the trial number of replacement weapons of a given type sent to divisions is reduced due to inventory shortages, then trial numbers of weapon replacements of other weapon types are proportionally increased (proportionality based on the value of weapons by type). The trial numbers of replacements for the other types of weapons are increased until: (1) Divisions do not need any more weapons of that type, or (2) Weapon replacement pool runs out of that type weapon, or (3) Divisions receive enough other weapons of other types to equal the value of the weapons it originally required but did not get due to shortage of that type weapon in the replacement pool.

The number of replacement weapons, by type, considering these calculations, is the actual number of replacement weapons of that type sent to the divisions.

The actual number of personnel replacements by division, is based on the preceding calculation of the actual number of replacement weapons. The calculation which is used prevents the actual number of personnel replacements from causing the percent personnel strength to exceed a "maximum" weapons strength--where this "maximum" weapons strength is the sum, over all types, of the values of each type of weapon actually in the division divided by the total value of all weapons in full TOE strength divisions.

The personnel replacement calculation permits the percent of personnel strength to be no greater than the percent weapon strength (which is dependent on the composition of enemy forces), and the number of personnel replacements goes to zero as the total number of weapon replacements goes to zero.

The allocation logic described may be overriden by specific day-by-day allocations and force movements input by the user. This would be necessary if, for example, a unit replacement policy or some combination of unit and individual replacement policies were desired.

a. <u>User Inputs</u>

- "Pipeline" factor, which is multiplied in the model by the current personnel strength in all divisions to establish a maximum number of replacements which can be accepted per day.
- Initial number of ground weapons, by type, in each type of division, by sector.
- TOE authorized number of ground weapons, by type, in each type of division.
- Initial number of personnel in each type of division, by sector.
- TOE authorized personnel in each type of division.
- Number of divisions, by type, in each sector. This input is not adjusted for actual strength of divisions, e.g., if there are 2 divisions in sector with 75 percent strength, then the number of divisions present is 2, not 1.5.

- The number of replacement weapons, by type, entering the theater each day.
- The number of replacement personnel entering the theater each day.
- The number of units, by type, entering the theater each day.

b. Inputs Generated by the Model

- Number of personnel in each type of division in each sector and region. This value is input for the first day and subsequently updated daily by the model.
- Number of weapons, by type, in each type of division in each sector and region; updated daily after first day.
- Number of weapon and personnel replacements necessary to bring each division up to authorized strength, daily.
- Number of weapons by type, in the weapon replacement pool, daily.
- Number of personnel in the personnel replacement pool, daily.
- Minimum value of each ground weapon. This is the daily kill potential of the weapon, given that all its fires are directed to the enemy target weapon against which it is least effective.
- Maximum value of each ground weapon. This is the daily kill potential of the weapon, given that all its fires are directed to the enemy target weapon against which it is most effective.

c. Output

- Number of personnel replacements sent to divisions, by type division, by sector or region.
- Number of replacement weapons, by type sent to divisions, by type division, by sector or region.

d. Assumptions

- Available personnel and weapon replacements are allocated according to need, with the following exceptions based on their relationship with each other: Personnel replacements should not be sent to a division if they would, in effect, have no weapons; and weapon replacements should not be sent to a division if there would

be insufficient personnel to man them.

- There is no distinction between divisions of a given type, in a given sector or region, in that their status is maintained as a single average status. Therefore, it is not possible to assign differing replacement priorities to divisions on the front lines and those in reserve.
- If built-in model logic is used, it is not possible to represent a "unit replacement" policy. This logic may be overriden and detailed inputs regarding the movement of forces may be used to represent that policy in a limited way.

3. LULEJIAN

The model treats the movement and allocation of both unit and individual replacements. Three types of battalions--infantry, mechanized infantry and tank--belonging to as many as six national participants per side may enter the theater. Individual personnel (riflemen) belonging to each national participant may also enter the theater, along with individual replacement items of equipment.

Upon arrival at the point of entry into the theater (port), the model permits the entry of resources to be constrained by a port input capacity. Since unit and individual replacements are given priority, it is not the intent in the model to apply constraints to the entry of these resources. However, the movement of these resources from the port to the front lines can be constrained by the capacity of the theater transportation system.

In the model, combat units use their own vehicles for movement from the theater port to the combat sectors. Therefore, the only movement delays they encounter are caused by limitations in the capacity of the road network.

When combat units emerge from the road network, they are assigned to the single theater pool of reserve units for later allocation to combat sectors. Units in the reserve pool, including those arriving into the theater, are allocated

daily to the sectors on the basis of the offensive/defensive postures to be used the following day, the FEBA movement in the sectors, the initial deployment of forces in the sectors, and the type and nationality of the unit in question.

The movement and allocation of individual personnel and equipment replacements is different from that of incoming combat units. The individual replacements are dependent upon airlift aircraft and the general transportation vehicles in the logistics system for movement forward from the port. Priority for airlift aircraft is given to individual replacements; if additional capacity is available, general supplies are airlifted. Requirements for ground transportation vehicles are generated by the numbers of individual replacement resources available for movement and by the demands for supplies. If the required number of vehicles is greater than the available number, equal fractions of the resources competing for them will be transported. After their exit from the transportation system the individual equipment replacements are allocated according to relative needs.

Ground force allocation calculations are performed last in the model, at the end of each day of combat. The order of calculation is:

(1) The number of battalions in each combat sector that are to enter the pool of "fought out" units is calculated. The calculation is based on the cumulative probability of survival of the original members of the combat units. The probability of survival is computed as in the following example. If the loss rate on day 1 is 7 percent and on day 2, 5 percent the probability of survival (P.S.) after the 2 days would be computed:

$$P.S. = (1 - 0.07)\ (1 - 0.05) = 0.8835$$

The computed daily average probability of survival is compared to input threshold values to determine the number of fought-out battalions. The input threshold values may differ by side, national participant and type of battalion. The threshold value used on a given day depends on the P.S. and whether the battalion is attacking or defending.

(2) Allocation of individual infantry replacements to battalions on-line in the sectors, to reserves, and to fought-out battalions from the logistics network is made on the basis of need and nationality. Four user options are permitted:

(a) Pure unit replacement policy--where replacements are first sent to reserve battalions to build them to TOE level. Any excess replacements remain in the replacement pool, and are never used to replace losses in on-line battalions.

(b) Modified unit replacements policy--where replacements are first sent to reserve battalions to build them to TOE level; any excess replacements are sent to fought-out battalions. If any excess replacements still exist they are sent to on-line combat units.

(c) Modified individual replacement policy--where replacements are first sent to on-line battalions in the combat sectors to reach TOE levels. Excess replacements are sent next to reserve units, and then to fought-out battalions.

(d) Pure individual replacement policy--where replacements are sent to on-line battalions in combat sectors to TOE levels; any excess replacements are retained in the replacement pool.

(3) After a period of rest and recuperation, fought-out battalions are permitted to exit that pool and enter the reserve pool for subsequent allocation to combat sectors as new battalions.

(4) Reserve battalions are then allocated to sectors.

a. <u>Inputs by User</u>

- Number of individual infantry replacements, by nationality, received at the ports of each side.
- Replacement policy option--choice of allocation of individual replacements, by type and nationality, to:

(a) Reserves only

(b) Reserves, fought-out battalions, on-line battalions (in order).

(c) On-line battalions, reserves, fought-out battalions (in order).

(d) On-line battalions only.

- Critical value of cumulative probability of survival at and below which a battalion, by type and nationality, is considered totally combat ineffective. Such battalions are required to spend an input number of days in a pool of fought-out battalions in order to recover full combat strength.
- Number of days required for fought-out battalion to recover.

b. Inputs Generated by the Model

- Number of casualties per battalion, per type and nationality, per sector, per day; and also their net strength.
- Daily value of the average cumulative probability of survival by type of battalion.

c. Output

- Number of battalions in each sector, by nationality, entering the pool of "fought-out" units per day.
- Number of replacements allocated to each battalion, by type and nationality, per day.

d. Assumptions

- Individual personnel replacements have priority over general supplies when being airlifted only. No similar priority exists in the utilization of empty ground logistics vehicles.
- Replacements, unit and individual, are allocated on the basis of need, as units sustain casualties and lose combat effectiveness.
- At sufficiently high levels of exposure to combat, expressed as a threshold value of the cumulative probability of survival of the original unit members, units become totally combat ineffective.
- Four options in allocation of replacements are possible:

  (a) Replacements for reserve units only to the TOE level.

  (b) Replacements (in order of priority) for reserves, fought-out units, and on-line units.

(c) Replacements (in order of priority) for on-line, reserve, and fought-out units.

(d) Replacements for on-line units only, to the TOE level.

- Individual infantry replacements are split between infantry and mechanized infantry battalions according to needs.
- Individual infantry replacements are associated with a particular national participant and are allocated to on-line, reserve, or fought-out battalions of that national participant only.
- Daily need for replacements in specific battalion types and nationality is proportional to the difference between their TOE strengths and actual end-of-day strengths.
- Allocation of reserve battalions, by type and nationality, to combat, can be accomplished in one of several ways:

(a) Fraction of reserve battalions which may be deployed each day input by the user.

(b) Allocated in proportion to the deployment on the initial day of combat.

(c) Allocated in proportion to today's FEBA movement in each sector.

(d) Allocated on the basis of posture for the following day. (No allocations are made to sectors where neither side is attacking, or to sectors where the allocating side is in a delay posture.)

4. VECTOR

Replacement personnel and units may be allocated to sectors upon their arrival in the theater. The allocations are controlled by user-specified tactical decision rules. Units may be sent directly to the FEBA in some sector, or they may be allocated to sector replacement pools. Except for the case of units sent directly to the FEBA, all replacement personnel, whether they arrived in a sector as individuals or as part of a unit, are accounted for in a single pool. The same is true for each type of maneuver unit weapon. The battalion-level

(for Red, regimental-level) organizational headquarters, as opposed to their component elements, are accounted for, by type, in a separate pool in each sector. Allocations of personnel replacements are made by the tactical decision rules directly from the sector personnel pools to the battalion areas.

The user may design tactical decision rules to reflect any individual replacement scheme desired, or he may choose one of five options made available in the model. In each of the five available options, the rules must first determine the total available replacement personnel to be assigned to each type of battalion at the FEBA, for the period. Then, the rules may set a variable (IRPOP) to (1) assign these replacements to individual battalion areas on a completely rule-determined basis, (2) average the number of personnel among all forces of the same type in the same sector, (3) assign replacements in proportion to the difference between the present force level and its TOE level, (4) assign replacements in proportion to another rule-determined measure of replacements required (e.g., 85 percent of TOE), or, (5) assign replacement personnel at a rate to make battalion combat units approach a constant strength, regardless of daily attrition.

The allocation of units from the sector pools to the FEBA is also controlled by the user-input tactical decision rules. When the decision to commit a given type of unit is made, the headquarters organization of that type is removed from its pool. The unit being committed is then provided its personnel and materiel components from the individual sector pools. The makeup of units being committed is controlled by tactical decision rules. It may be based on such considerations as the TOE of the unit and the relative priorities chosen for assignment of resources to units being committed and those already at the FEBA.

In VECTOR, the replacement pools are also the reserve pools. Therefore, the rules of allocating newly arrived units in those pools are the same as those for committing reserve units in general. Also, the individual and unit headquarters pools may receive resources other than new arrivals in the theater. These resources may come from units or individuals transferred among sectors, or, after some time delay, units which have been withdrawn from the FEBA. No personnel are represented as returning for duty after recovery from wounds. These movements are controlled by the tactical decision rules.

If desired by the user, some or all newly arriving unit headquarters and component elements may be allocated to theater pools for subsequent reallocation to sectors. As with the other personnel and unit management functions, this process is controlled by input tactical decision rules.

a. <u>Inputs by User</u>

- TOE strength of each type of unit. The units are approximately the size of battalion task forces for Blue, and are approximately regimental size for Red.
- Initial strength of units, by type.
- Initial numbers of units and their component elements in sector and theater replacement/reserve pools.
- Schedules of individual and unit arrivals in the theater.
- Tactical decision rules regarding arrival, assignment, and replacement of personnel. (Tactical rule entries #17, 3, and 19 respectively.)
- Method of assignment of personnel replacements to battalion areas (IRPOP = 1-5).
- Other input data selected by the user as part of the criteria to be used by the tactical decision rules.

b. <u>Inputs Generated by the Model</u>

- Updated strengths in each battalion area and in the sector and theater replacement/reserve pools, daily.

- Other data generated by model which is selected by the user as part of the criteria to be used by the tactical decision rules.

c. Outputs

- The number of replacement personnel and replacement/reserve units allocated to the theater pool, each sector pool, and to the battalion areas (FEBA), daily.

d. Assumptions

- Personnel are completely interchangeable with each other. No differentiation with respect to skills, training or experience is made.
- Units may be efficiently formed from pools of unit headquarters elements and pools of each of their significant component elements, including personnel. Such units may then be committed to combat with no intervening delay. (An alternative assumption is that units can retain their efficiency regardless of the numbers of personnel and equipment replacements they are required to absorb prior to being committed to combat.)
- Personnel replacements are at full efficiency immediately after assignment to units in combat. That is, the presence of a large percentage of newly assigned personnel causes no degradation of unit effectiveness.
- No casualties recover sufficiently for return to duty.

5. DISCUSSION

Each of the models accounts for individual personnel replacements, allocating those which arrive in theater to replacement pools at various levels. Except for IDAGAM, the models do not consider non-combat personnel. The treatment of non-combat personnel in IDAGAM is not extensive, in that they do little but consume supplies and become casualties. Further, none of the models makes any distinction as to the types of combat personnel, e.g., tank crewmen, rifleman, or their skill levels, e.g., NCO's and private soldiers. Only the LULEJIAN model permits the limitation of assigning replacements only to units of their own

nationality. Six nationalities can be represented for each side. Differing schemes for allocations of replacements are available for use in the different models. None of them was found to be illogical. The technique used to maintain a balance between personnel and weapons strengths in IDAGAM has merit; even though at a relatively high level of abstraction, it mitigates against serious imbalances between the numbers of weapons on hand and the personnel to operate them. The problem of imbalance does not arise in the LULEJIAN model, because the only individual personnel replacements it treats directly are riflemen. Personnel associated with major ground weapons systems are present (and vulnerable) in the LULEJIAN model, but they are treated only as adjuncts to the equipment itself. There are no built-in procedures in CEM and VECTOR to prevent imbalance. If desired, the user could design such a system for VECTOR and program it into the tactical decision rules.

The tactical decision rule technique in VECTOR permits more flexibility in personnel replacement policies than is possible in the other models. The next most flexible is LULEJIAN, which provides four replacement policy options. CEM allows a choice from two replacement options on the Red side, but the single Blue replacement policy is fixed in the model. IDAGAM allows essentially no variations from the single policy built into the model. IDAGAM personnel policy can be changed only by overriding the model logic and describing replacement activities by detailed inputs for each day.

All the models have adequate aggregated representations of the personnel replacement function, considering the purposes for which the models should be used. None of them is suitable for detailed analysis of personnel requirements or policies.

Q. UNIT INEFFECTIVENESS

1. CEM

The effectiveness of an on-line unit is considered a function of its "state." The state of a unit at any given time is defined as the ratio of the current firepower score to the score which the unit would have if it possessed all authorized equipment and personnel, and if supply levels were completely adequate. (This ratio, less than or equal to 1, is multiplied by 100 within the model for convenience, so state values range from 0 to 100.) The criteria and procedures pertaining to ineffectiveness of Red and Blue units are different.

For Red divisions, the model attempts to portray a doctrine of echelonment and depletion of on-line divisions while previously exhausted divisions are being rebuilt. At the beginning of the corps (Red Army) cycle, the state of each on-line and reserve division is compared with an input threshold value. If the state of a Red division is below this threshold, and if at least 2 divisions will remain available to the parent Red Army, the division is considered decimated and is withdrawn for rebuilding. The frontage of the stronger on-line diviison which was adjacent to the withdrawn division is then expanded to fill the gap. The decimated division is tagged for return to the same parent army after being rebuilt. Rebuilding is considered adequate when replacement weapons and personnel cause the division state to reach or exceed an input threshold value, and after an input minimum time has elasped. The threshold state value used to determine the adequacy of rebuilding differs from the threshold for initial decimation. Rebuilt divisions can be used as needed to reinforce the appropriate army during the next army cycle.

The procedures pertaining to ineffective Red units are for the most part fixed and cannot conveniently be changed by the model user. In one respect, however, an option is available.

A "switch" is provided to allow the user to control assignment priorities for replacement weapons and personnel. They may either be allocated with equal priority to all divisions, decimated or not, or they may be allocated only to decimated divisions. If the user elects to have them assigned only to decimated divisions, the stronger (in terms of state value) get priority.

For the Blue side, the units which can become relatively ineffective are brigades, rather than divisions. The state of each on-line brigade is compared to an input minimum value. Brigades whose state values are less than the threshold are considered excessively weak. A weak brigade cannot be withdrawn from combat, however, unless a stronger reserve brigade in the same division is available to replace it. If it can be withdrawn, the weaker withdrawn brigade then becomes the reserve for its parent division.

a. Inputs by the User

- Threshold state values below which on-line Red divisions are considered decimated. Two values, applying to all type divisions, are input: One for when the parent corps is on the attack, and one for defense.
- Minimum time which must elapse before a decimated Red division can be considered rebuilt.
- Minimum state value which a decimated Red division must have before it can be considered rebuilt. This is separate from the threshold values in paragraph a, above.
- Choice of 2 allocation options for Red replacement weapons and personnel:

  (1) Allocate to all divisions, decimated or not, with equal priority, or,

  (2) Allocate only to decimated divisions, with those having higher state values getting priority.

- Threshold state value below which a Blue brigade is considered excessively weak. Such a brigade will be replaced on line by a stronger reserve brigade if one

is available. If there is no reserve brigade in the same division, or if the reserve brigade is not stronger, the weak brigade remains on line.

b. Inputs Generated by the Model

- Current state of each Red division and Blue brigade.
- Number of Red divisions in each of the Red armies.
- Status of each Red division: On-line, reserve, or decimated and being rebuilt.
- Status of each Blue brigade: On-line or reserve.
- The number of replacement weapons and personnel available for assignment to units of each side.

c. Outputs

- Designation of Red divisions which have become decimated during each division cycle.
- Designation of the previously decimated Red divisions which have been rebuilt and are available for reinforcement of on-line forces.
- A list of Red divisions in the decimation pool, and the amount of time each of them has spent there.
- Designation of the excessively weak Blue brigades which have been removed from the front lines, placed in reserve status, and replaced by a stronger brigade which was previously in reserve.

d. Assumptions

- A Red doctrine of echelonment and unit replacement can be represented by the following:

  (1) Allowing on-line divisions to become decimated through combat attrition while receiving no replacement weapons or personnel.

  (2) Allocating all available replacement weapons and personnel to rebuild divisions which have been decimated and removed from the front lines.

- The necessity of withdrawing a unit from combat is a function of the "state" of the unit. Unit state is defined as the ratio of the current total unit firepower score to the unit firepower when all personnel

and equipment authorized by its TOE are on hand. (Loss rates and/or the amount of time a unit has been in combat do not as such have a direct bearing on unit effectiveness.)

- No Blue units larger than brigades become sufficiently ineffective to be withdrawn from combat. The larger units are withdrawn only in order to reconstitute reserves.
- A severely weakened Blue brigade is withdrawn from combat only if a stronger reserve brigade is immediately available to replace it.

2. IDAGAM

The model simulates the withdrawal of units from combat when they become ineffective because of attrition. Unit effectiveness is assumed to be dependent on personnel strength and weapons strength. A threshold effectiveness value below which a division is considered ineffective is input by the user. The threshold is in terms of percent of full, or TOE, effectiveness. The actual effectiveness value which is compared to the single threshold value is the smaller of two values: The effectiveness based on weapons strength, and the effectiveness based on personnel strength. For weapons, the actual percent effectiveness is the same as the percent of TOE authorized weapons on hand. For personnel, a user-input table is used to determine the percent effectiveness as a function of the percent of authorized personnel on hand. This allows the percent reduction of effectiveness due to personnel losses to be greater than the actual percent losses of personnel.

The effectiveness of divisions which have been withdrawn to the rear can subsequently be improved by the assignment of replacement weapons and personnel. Additionally, the degradation of effectiveness due to personnel losses may partially be obviated by reorganization. In the model, reorganization, and hence the improvement in effectiveness, is a function of time. In no case, however, can reorganization cause the overall percent effectiveness of a unit to be greater than either the

percent personnel strength or the percent weapons strength on hand.

When the overall percent effectiveness of a withdrawn division exceeds an input threshold value, the division can again be used in combat.

Since no distinction is possible among divisions of a given type in a given sector, all such divisions are considered to have the same, average effectiveness. Therefore, all units of a given type in each sector become ineffective simultaneously, and they regain effectiveness at the same time.

At the option of the model user, the automated withdrawal of units described above may be overridden. All division movements may then be preplanned outside the model, and directed to occur on specific days. (All forces in the model can be moved in this manner.) Since these preplanned movements do not depend upon internal model logic, the remainder of this section is applicable only to the automated movements.

a. Inputs by the User

- Numbers of weapons and personnel authorized for each division, by type.
- Threshold percent effectiveness below which divisions will be withdrawn from combat.
- Percent effectiveness as a function of percent of authorized personnel on hand. This value reflects only the effectiveness degradation caused by a shortage of personnel, and does not consider shortages of weapons or the possible enhancement of effectiveness due to reorganization.
- The reorganization rate for ineffective divisions. This is the rate at which lost effectiveness caused by personnel shortages can be regained through the passage of time. Percent effectiveness cannot become greater than the percent of authorized personnel (or weapons) on hand.
- Threshold percent effectiveness value above which a previously withdrawn unit is again considered effective

and eligible for recommitment to combat.

b. Inputs Generated by the Model

- Actual numbers of personnel and weapons on hand, by division type, by sector.

c. Outputs

- Number of ineffective divisions withdrawn from combat during each time period by division type, by sector.
- Number and effectiveness status of units which have been withdrawn and are not yet effective enough to be recommitted to combat.
- Number of previously withdrawn units which become effective enough for recommitment to combat during each time period.

d. Assumptions

- The effectiveness of a combat unit is a function of the percent of authorized weapons and personnel on hand.
- Reorganization, represented by the passage of time, can increase the effectiveness value associated with personnel shortages. It has no effect on the value associated with weapons shortages.
- Within each sector, all units of a given notional type have the same number of weapons and personnel on hand at all times. Therefore, when one such unit becomes ineffective, they all do.

3. LULEJIAN

Unit ineffectiveness in the LULEJIAN model is dependent on combat losses over a period of time. It is not determined merely by comparing the fraction of authorized weapons and/or personnel on hand at specific points in time to some threshold value. The technique used is intended to account for fatigue and psychological factors which are not necessarily reflected in a unit's current strength. For example, replacement can be adequate to maintain the strength of a unit at or near its

authorized level, regardless of the intensity of combat it has experienced. LULEJIAN postulates that combat losses over a period of time can cause a unit to become ineffective even though it receives a sufficient number of replacement weapons and personnel to maintain it at an adequate strength.

The effectiveness of a unit is assumed to be a function of the probability of survival (P_S) of the original members of the unit, that is, those which were in the unit when it was committed to combat. P_S is calculated as in the following example from the model documentation:

If the attrition rate per day is a constant 5 percent, the average probability of survival at the end of n days of battle (P_{S_n}) would be

$$P_{S1} = 0.95$$

$$P_{S2} = (0.95)^2$$

$$\vdots$$

$$P_{S_n} = (0.95)^n$$

For each type of maneuver battalion, a threshold value of P_S is input. There may be different P_S values for attack and defense. Units with a P_S for original members at or below this threshold are considered ineffective. The "tactical resolve" or maximum acceptable attrition rate used in attrition and FEBA movement calculations is degraded linearly with reduced P_S, and becomes zero at the threshold P_S value. Each day, units whose P_S is at or below the threshold are removed from combat and placed in a "fought-out" pool for rest. Units in the fought-out pool may also receive replacement personnel and equipment, depending on the replacement policy option chosen. In any event, battalions must rest in the pool for an input number of days. They then become eligible for combat as if they were newly

assigned to the theater and the probability of survival of battalion members again takes on an initial value of 1.

The LULEJIAN model does not account for individual battalions of a given type in a given sector. Only average values for P_S and strength are maintained. To determine the number of individual battalions which are ineffective during each time period, a uniform distribution of P_S around the average is assumed. That is, as many battalions have a P_S above the average as below; the difference between the minimum P_S and the average P_S is the same as the difference between the average P_S and unity; and the P_S values for all battalions are uniformly distributed between unity and the minimum P_S. With this assumption, the number, if any, of battalions with P_S values below the threshold for ineffectiveness is determined. If any battalions are withdrawn, the average P_S of those remaining is simply the sum of 1 plus the ineffectiveness threshold value, divided by 2.

The average strengths of the fought-out battalions and the battalions remaining on line are determined through a similar assumption: That the strength of the battalions varies linearly with the probability of survival of the battalions. Thus, when the weaker battalions are withdrawn, an immediate effect is to increase the average on-line strength, as well as the average P_S.

The developers of the LULEJIAN model have provided an analysis of certain historical data from World War II and the Korean War to support the use of cumulative probability of survival in determining unit ineffectiveness. The analysis is set forth in a LULEJIAN and Associates report by R.D. Daniels entitled, "Factors that Mitigate the Intensity Level of Ground Combat," dated December 1972.

a. Inputs by the User

- Threshold values of probability of survival below which a unit is considered ineffective, by unit type, for attack and for defense.
- Number of model time periods (days) which an ineffective unit must spend in the "fought-out" pool before it is capable of again engaging in combat.
- Authorized weapons and personnel strengths of units, by type and nationality.

b. Inputs Generated by the Model

- Daily average attrition of weapons and personnel by type and nationality of unit, by sector.
- Updated average strengths of units, by type and nationality, by sector.
- Updated numbers of units, by type and nationality, in each sector.

c. Outputs

- Number of battalions withdrawn each day to the fought-out pools, by type and nationality, by sector.
- Updated number of battalions, by type and nationality, in the fought-out pool, and the number of days each has been there.
- Number of battalions which have completed their rest period in the fought-out pool and are thus eligible for recommitment to combat, by type and nationality.

d. Assumptions

- Combat ineffectiveness of a maneuver battalion is a function of the cumulative probability of survival (defined above) of the personnel who were in the unit at the time it entered combat. The receipt of replacement personnel has no effect except to dilute the attrition of the original members of the unit.
- The cumulative probabilities of survival of battalions of a given type and nationality in a given sector are uniformly distributed around the mean cumulative probability of survival of such units.

- The strengths of battalions of a given type and nationality in a given sector are uniformly distributed around the mean strength of all such battalions. A linear relationship between cumulative probability of survival and personnel strength is also assumed.
- Fought-out units regain their ability to engage in combat by resting in a rear area. Although replacement weapons and personnel may be received, they are not necessary to the rejuvenation process.

4. VECTOR

There is no built-in logic in VECTOR to control the withdrawal from combat of units which are no longer effective. Tactical decision rules can be designed by the user to accomplish this, incorporating any desired criteria to determine ineffectiveness. Logic is provided in the model to delay the possible recommitment of units for up to 5 model time periods after their withdrawal. This feature can also be modified by means of the tactical decision rules.

5. Discussion

Three of the four models, CEM, IDAGAM, and LULEJIAN, contain logic for temporarily withdrawing units from front line combat when some measure of their condition becomes lower than an input threshold value. The fourth, VECTOR, relies on the tactical decision rule structure and on logic formulated by the user to accomplish removals of units. As with many other aspects of the VECTOR model, the techniques employed may be as sophisticated as the capabilities and resources of the user permit. For this reason, the VECTOR model will not be further discussed in this section.

For the other three models, it is important to remember that "effectiveness" as used in this context does not refer simply to the relative inability of a military organization to perform the functions for which it was designed. Rather, it refers to a condition which renders a unit so incapable of

performing its functions that it must be temporarily removed from combat. That is, the unit has reached some "breakpoint" and can no longer continue to employ that portion of its authorized weapons and personnel which are still available.

In CEM and IDAGAM, complete unit ineffectiveness is assumed to be directly related to the fraction of certain authorized resources which are on hand during each specific time period. (As stated in paragraph 1 above, the CEM model assumes that only Red units become so decimated as to require their temporary removal from combat for rest and rebuilding.) Except for the "reorganization" feature in IDAGAM, neither model directly considers casuality rates, total time in combat, nor the intensity of combat. For example, units whose losses during each time period are immediately replaced will remain at full effectiveness, regardless of the rate or magnitude of those losses.

In contrast to CEM and IDAGAM, the LULEJIAN model assumes that a unit reaches an ineffectiveness breakpoint because of the cumulative effects of prolonged combat. Specifically, a unit becomes ineffective when the cumulative probability of survival of the original members of the unit falls below an input threshold value. ("Original" members are those who were in the unit when it began its current period of combat.) As such, the receipt of replacements does not improve the status of the unit with respect to the breakpoint, although the arrival of new personnel may subsequently tend to dilute the attrition of the original members.

It seems intuitively obvious that fatigue and psychological factors have a great effect on the ability of a unit to continue to engage in combat. Therefore, the measurable aspects of a unit's condition which are used to assess the ability to continue in combat are to a considerable degree surrogates for those factors. (If a depleted unit retains the ability to

employ each of its remaining weapons about as effectively as stronger units, it makes little sense to require that it be withdrawn from the front lines while it is being rebuilt.)

No theoretical justification is presented for the methodologies of either CEM, IDAGAM or LULEJIAN. The LULEJIAN developers do, however, present an analysis based on selected historical data which tends to support the formulation used in the model. For this reason, and because it more explicitly considers the effects of prolonged combat, the LULEJIAN model is perferred in this respect to either CEM or IDAGAM.

In general, the methods used in each model to determine when withdrawn units are sufficiently rehabilitated to allow their recommitment are consistent with the determinations of ineffectiveness. In LULEJIAN, rehabilitation is a function of time only. Therefore, it is possible for seriously understrength units to be made fully ready for combat albeit with less than full combat capability. CEM and IDAGAM require that units have specified fractions of authorized resources on hand. In addition, CEM can require that unit spend a specified time recuperating. Given the basic assumptions of each model regarding criteria for ineffectivenss, their representations of rehabilitation are considered to be about equally good.

The degree to which individual units are identified in determinations of ineffectiveness varies considerably among the 3 models. CEM accounts for each unit individually. Unit effectiveness is determined directly with no averaging necessary. IDAGAM categorizes units according to notional type, while LULEJIAN categorizes them according to notional type and nationally. Both IDAGAM and LULEJIAN actually store a single average effectiveness value for all the units in a given category. The LULEJIAN model then assumes a uniform distribution of the effectiveness values of the individual units of a given type and nationality around the average value. Therefore, it is

normal for no more than a portion of the units of a given category in a given sector to become ineffective during a single time period. In contrast, all IDAGAM units of a given type in a sector are assumed to be identical in all respects. Therefore, no units of a type will be withdrawn until their average effectiveness falls below the threshold. When it does, then all units of that type are withdrawn at once. This unrealism in IDAGAM can be overcome by an extremely large increase in the number of notional unit types. Computer storage requirements would be increased accordingly.

CEM is considered superior to the other models in the ability to represent the effectiveness of individual units, with LULEJIAN next, and IDAGAM the poorest.

Overall, LULEJIAN is considered best in this functional area, with CEM and IDAGAM about the same. An option to allow Blue units to be withdrawn for ineffectiveness is needed in CEM, and IDAGAM needs greater resolution of units.

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R. INEFFECTIVE NEW TROOPS

1. CEM

Personnel replacements reaching on-line divisions need not be immediately available for combat. A delay to allow them to be assimilated into their assigned units can be represented through the use of assimilation pools. As each group of replacement personnel arrives at division level an input fraction of the group is placed in one of ten available pools. (The input fraction for any particular pool or pools can be zero.) They are then made capable of performing in combat according to the following scheme: Personnel in pool number one are immediately ready for combat, that is, in the division cycle during which they arrived. Those in the second pool become ready during the next division cycle after arrival; those in the third pool in the third division cycle, and so on. Combat-ready personnel who are not needed are retained for subsequent assignment. They can then be assigned immediately when there is a need for them. Since the fraction of new arrivals which is placed into each pool is controlled by the user, the average assimilation time may be any amount from 0 to 9 division cycles.

a. Inputs by User

- The number of replacement personnel arriving in the theater during each division cycle.
- The fraction of replacement personnel arriving at division level which is placed in each of 10 possible assimilation pools. As desired by the user, the fractions for some of the pools may be zero.
- The authorized personnel strength for each division.

b. Inputs Generated by the Model

- Updated personnel strength of each division, by division cycle.

- The number of personnel replacements allocated to each division by higher headquarters during each division cycle.

c. Outputs

- The number of personnel replacements who become ready for combat in each division during each division cycle.
- The number of personnel replacements being held in each of the assimilation pools for each division during each division cycle.

d. Assumptions

- The inability of newly assigned personnel to participate effectively in combat can be represented as a delay in their assignment to the front lines.
- The time necessary for the assimilation of newly assigned replacement personnel remains the same throughout the course of a campaign (i.e., a single model run). It is unaffected by the ongoing combat situation.

2. IDAGAM

A delay in the attainment of full effectiveness by newly assigned replacement personnel can be represented in IDAGAM. The effectiveness of replacement personnel is expressed as a fraction of full effectiveness. In the model the fractional effectiveness is multiplied by the number of personnel with that effectiveness to obtain an equivalent number of fully effective personnel. That equivalent number is considered available for subsequent computations in the model, e.g., attrition calculations.

a. User Inputs

- The number of days after arrival in a division that is required for newly assigned personnel to become fully effective. This is input as a model dimension; the values of 2 and 5 have been used in past model runs.

- The fractional effectiveness of new replacement personnel, as a function of the number of days they have been assigned to a unit.

b. Inputs Generated by the Model

- The number of replacement personnel arriving at each division, by type and geographic location, by day.

c. Outputs

- Equivalent number of fully effective personnel represented by the partially effective personnel replacements on hand, by type of division, by location, by day.
- Inventory of the partially effective new personnel on hand, and their fractional effectiveness.

d. Assumptions

- Two soldiers at "50% effectiveness" are equivalent to one soldier at "100% effectiveness". This assumption defines "fractional effectiveness" as used in the model.
- The time necessary for newly assigned personnel replacements to attain full effectiveness remains the same throughout the course of a campaign (i.e., a single model run). It is unaffected by the ongoing combat situation.

3. LULEJIAN

No capability exists in the model to simulate the ineffectiveness of new troops assigned to combat units. To a degree, the user may represent it indirectly by adjusting the schedule for replacement arrivals which is input to the model.

4. VECTOR

As in LULEJIAN, there is no capability in the VECTOR model to simulate ineffective new personnel. Again, this may be accounted for to an extent by adjusting the input schedule for arrivals.

5. Discussion

Two of the four models, CEM and IDAGAM, have provisions for internally representing the effectiveness of newly assigned personnel replacements as less than complete. Although two different techniques are used, reduced effectiveness in both CEM and IDAGAM is represented by a delay in the complete assimilation of replacements.

Neither LULEJIAN nor VECTOR can internally represent delays in the attainment of full effectiveness by replacements. Much the same effect can be realized, however, by adjusting the replacement arrival schedules. In the case of these two models, delays would then occur before the replacements arrive in the theater, rather than after their assignment to combat units. The basic difference in the two approaches is in the vulnerability of the replacements. In CEM and IDAGAM, they can become casualties before attaining full effectiveness; in LULEJIAN and VECTOR they cannot.

S. MEDICAL

1. CEM

Of the total number of combat casualties assessed by means of the attrition equations, an input fraction is killed, another input fraction is wounded, and the remaining casualties are considered missing or captured. The input fractions may be different for different types of engagements. The wounded then receive medical treatment in one of three ways. A user-input fraction of the wounded goes to local aid stations for treatment of minor wounds; another fraction is evacuated to hospitals in the theater; and the remaining fraction is evacuated out of the theater.

The wounded who are treated at the local aid stations are sent back to their units during the next division cycle. They are then ready for combat. Those who are evacuated out of the theater are permanently lost. The wounded who are sent to hospitals in the theater are given medical treatment for an input amount of time, and are then considered recovered. After their recovery, they are assigned to theater replacement pools. They are then eligible for subsequent reassignment to combat units during the next theater cycle. When personnel who have recovered are transferred to the replacement pool, they become equivalent to newly assigned replacements. No effort is made to reassign them to their former units.

Personnel in CEM may also become killed or injured from non-combat causes, and they may contract disease. Input fractions of all personnel in the theater, on each side, are so afflicted during each time period. The system for the medical treatment of the diseased and those with non-battle injuries is analogous to that for combat casualties. Different fractions than those for combat casualties are used to determine the numbers who are treated locally, evacuated to theater hospitals, and evacuated from the theater.

However, their recovery time in the theater is the same as the recovery time for those who were wounded in combat.

a. Inputs by the User

- Fraction of combat casualties during each time period which are killed and the fraction wounded, by type of engagement.
- Fractions of the wounded during each time period which receive medical treatment in each of the following ways:
  - Treated locally at battalion aid stations.
  - Evacuated to theater hospitals for treatment.
  - Evacuated out of the theater for treatment.
- Fraction of the total personnel in the theater, by side, who contract disease or suffer non-battle injuries (DNBI) during each time period.
- Fractions of DNBI personnel during each time period who are:
  - Treated at battalion aid stations.
  - Evacuated to theater hospitals.
  - Evacuated from the theater.
  - Average recovery time for personnel in theater hospitals for all causes.

b. Inputs Generated by the Model

- Number of casualties, by side and time period.
- Total number of personnel in the theater, for each side and time period.

c. Outputs

- Number of personnel treated locally and subsequently returned to duty in the next division cycle.
- Number of personnel evacuated from the theater during each time period, and the reasons for evacuation.
- Number of personnel evacuated to hospitals in the theater during each time period, and the reason for evacuation.

- Number of personnel who have completed recovery and are transferred to theater replacement pools during each time period.

d. Assumptions

- The simplified representation of the medical process described above, characterized by fixed input fractions and average recovery times, is adequate for theater-level combat analyses.

2. IDAGAM, LULEJIAN, AND VECTOR

In all three of these models, all personnel who become casualties are permanently lost. No distinction is made between killed, wounded, captured and missing personnel. There is no representation of medical processes. (Each of the models permits units, as opposed to individuals, to be withdrawn from combat under certain conditions. Withdrawn units may then be rehalibitated and returned to action. Details of these processes are covered in the section on "Unit Ineffectiveness".)

3. Discussion

Only CEM has any representation of medical processes. It is essentially accounting in nature, and highly aggregated. All basic issues pertaining to medical policies, activities, and capabilities must be resolved outside the model. CEM then allows the analyst to gain some appreciation of the effects of medical systems on the overall outcome of a theater conflict. In itself, the CEM model is not considered suitable for the comparison and evaluation of alternative medical policies or organizations, nor was it designed for that purpose. It does allow an examination of an aggregated medical system in the context of theater combat. The representation of medical activities in CEM is considered a useful feature of the model.

T. TRAINING

None of the models represents personnel training. CEM and IDAGAM can simulate a delay in the attainment of full effectiveness of newly assigned replacements. For some very limited applications, this might serve as a surrogate for in-theater training. Any other considerations of training time or readiness must be reflected in such user inputs as the arrival schedules for units and individual replacements.

U. INTELLIGENCE

1. CEM

Some effects of the intelligence process are represented in an aggregated way in CEM. The information concerning the enemy situation, which is used by commanders in their estimates is, in general, not the actual, current information. Instead, it consists of weighted averages of data describing the enemy situations during certain periods in the immediate past. At the beginning of each appropriate time period, the army, corps and division commanders on each side make estimates of the situation upon which they make certain decisions. These estimates involve a comparison of the capabilities of the commander's own forces with the capabilities of the enemy forces facing him. The procedures used in the model to estimate enemy capabilities are the same for army and corps levels. However, they differ at the division level. Both procedures are described below.

At army and corps levels, the estimates of enemy capabilities are based on the following: the estimated number of opposing battalions; the full-strength meeting engagement firepower scores of each estimated battalion; and the estimated state of each battalion. The "state" is a measure of an organization's combat effectiveness, and is the ratio of its on-hand to authorized firepower. The number of battalions estimated to be capable of undertaking the mission being considered at the beginning of a cycle (army or corps) is the weighted average of the numbers of battalions present at the start of the immediately previous cycle, and of the cycle before that. The weights assigned to the data for the two previous cycles are input by the user according to his estimate of the average delay in obtaining evaluated intelligence. These weights control the aggregated intelligence aspects of the model. Tactical air forces are not included in the estimates, and

consequently are not subject to the effects of the intelligence process which are represented in the model.

Enemy capabilities are estimated in the same general way by the division commanders as by the higher-level commanders. A major difference from the procedures at corps and army levels is that the full strength meeting engagement firepower scores are further modified by posture factors to provide estimated firepower values as a function of the tactical mission being considered. Also, the states of opposing battalions at division level are explicitly estimated by use of separate coefficients. The states of enemy units at corps and army level are estimated using the same coefficients as are used for estimation of their firepowers.

On the Blue side only, there is the capability to select an option which causes more recent information to be used in estimating enemy force capabilities. If the user desires, the number of estimated enemy battalions may be the weighted average of those actually present at the start of the previous cycle, and those present at the time the decision is made. Similarly, at division level, the states of the opposing battalions are based on the actual states during the current cycle and the immediately preceding cycle. This option allows the representation of more varied intelligence processing capabilities for the Blue side. The option is not available for the Red side.

a. Inputs by User

- Coefficients for weighting the actual data pertaining to the numbers of enemy battalions, and at division level, to their states. For estimates of the situation, these coefficients establish the relative importance of the enemy situation at the start of the immediately previous cycle and the situation at the start of the cycle before that. They, therefore, express the time lag in obtaining intelligence. For each side, the coefficients may be different for each

level of command and, at the division level, the coefficients for unit quantities and unit states need not be the same. Separate coefficients are input for estimating the quantities of each type of enemy maneuver battalion.

- Indication of the option chosen for the Blue side as to what time periods all the estimates are to be based upon. If the user so chooses, Blue's estimates may be based upon the actual enemy situation at the start of the current cycle and the one immediately preceding it.

b. Inputs Generated by the Model

- The number and states of the battalions which are capable of opposing the commanders at army, corps and division levels. This is given for the current cycle and the two cycles immediately preceding it.

c. Outputs

- Estimate of the numbers of opposing forces and their status.

d. Assumptions

- The effects of the intelligence process may be approximately modeled by using weighted averages of past actual data to determine estimated current data.

2. VECTOR

Some of the effects of intelligence can be represented in the VECTOR model by using the tactical decision rules. The rules may be programmed to select and store information concerning the status of forces on each side at battalion level. The stored information may then be retrieved and used by the opposing side as a basis for making decisions at a later period. The particular information stored and the types of decisions which are to be based on it are specified by the user. The length of time which the information is stored, and the consequent delay in obtaining useful intelligence is also controlled by the user. Storage for more than one time period is

possible. Longer retention times require more computer core space and involve the programming of relatively complex tactical rules by the user. Tactical rule entries 6 and 7 have been used in the simulation of intelligence on some test runs of the model. A one-day time delay for intelligence availability was simulated.

a. Inputs by the User

- Tactical decision rules to select information on the status of forces for storage.
- Tactical decision rules to organize and store the selected information.
- Tactical decision rules to retrieve the information at a later time for use in decision making.

b. Inputs Generated by the Model

- Selected information on the daily status of forces, down to battalion level, for each side, e.g., personnel strengths, weapons inventories, daily losses of personnel and weapons.

c. Outputs

- For the current time period, information concerning the actual forces which were opposing each side during some previous time period(s). This is the current simulated intelligence estimate.

d. Assumptions

- The effects of the intelligence process may be adequately represented by making daily estimates and decisions on the basis of actual information about opposing forces during some previous time period(s).

3. Discussions

Of the four models, only two, CEM and VECTOR, have any capability to simulate directly the effects of the intelligence process. This is accomplished in both CEM and VECTOR through

the use of information about the actual enemy situations in previous periods to make estimates and decisions for the current period. Because the process is controlled by user-specified tactical decision rules, the VECTOR model is the more flexible. Any combination of specific items of information and delays in their availability may be used. As the rules are made more complex, however, the amount of effort required of the user to design and program them also increases significantly.

In contrast, the logic for representing delays in obtaining intelligence is fixed in CEM. The user may vary only the relative weights to be applied to the two previous cycles for estimates by the Red side. For the Blue side, there is an additional option of considering the weighted average of the current cycle and the one immediately preceding it. Because the logic is fixed, the representation of intelligence in the CEM model requires less user effort than VECTOR.

The representation of less than perfect intelligence, which is present in CEM and VECTOR, is distinctly better than the assumption of perfect knowledge of the current enemy situation. The representations in both models are simplistic, however, and do not permit any sort of examination of the intelligence process itself.

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